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# ANNUAL REPORT

OF

# THE PENNSYLVANIA STATE COLLEGE

## 1899-1900.

[From January 1, 1899, to June 30, 1900.]

PART I—DEPARTMENTS OF INSTRUCTION.
PART II—AGRICULTURAL EXPERIMENT STATION.

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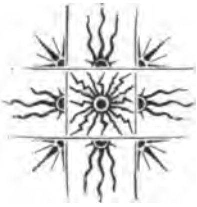

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# REPORT

OF

# THE PENNSYLVANIA STATE COLLEGE,

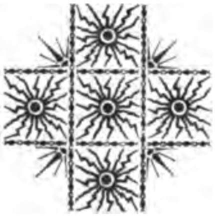
## FOR THE YEAR 1899-1900.

Harrisburg, Pa., June 30, 1900.

To the Senate and House of Representatives of the Commonwealth of Pennsylvania:

I have the honor herewith to transmit the Treasurer's report of the receipts and expenditures of The Pennsylvania State College, for the year 1899-1900, as required by law; and in connection therewith, the reports of the President of the College, and of Professors in charge of the departments of instruction. I venture to call attention to these reports as containing matter of great interest to the people of the Commonwealth.

JAMES A. BEAVER,
President of the Board of Trustees.



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# I.—PRESIDENT'S REPORT.

To the Board of Trustees of the Pennsylvania State College:

Gentlemen:—I have the honor to present herewith my report for the College year 1899-1900, accompanied by those of Professors in the several Departments of the College.

The following changes in the teaching staff have occurred during the year:

Professor Martin G. Benedict, in charge of the Sub-Freshman Class, resigned his position at the close of the last College year, and Assistant Professor John H. Leete was appointed in his place.

Dr. Henry T. Fernald resigned his position as Professor of Zoology to accept an appointment at the Massachusetts Agricultural College, and Miss Elizabeth B. Meek temporarily assumed charge of the work of his Department. Mr. Carl L. Becker was appointed Instructor in History and Political Science; Mr. Norman C. Riggs, Instructor in Mathematics; and Mr. C. M. H. Atherton, Assistant in the Chemical Laboratories. The only addition to the previous teaching force made by these appointments was in the case of Mr. Becker, by the appointment of whom much needed opportunity was provided for additional work in Political and Social Science.

During the year a long contemplated change has been made in the distribution of studies by dividing the work of the College year into two periods instead of three. This change will take effect at the beginning of the next College year, and the hope of the Faculty is that it will result in important advantages, especially by allowing concentration on fewer subjects at one time, with longer periods of continuous work. Under this arrangement the entire Fall Session will be given to advanced work with reviews and examinations immediately following the Christmas vacation. The second Semester will then follow immediately upon the close of examinations, with substantially the same distribution of time as during the first Semester. The experience of the College has been that many students have found difficulty in carrying the full work of the first Session, Freshman year, and have been unable to stand the test of examinations at its close. It is anticipated that the change proposed, by giving them their first reviews and examinations after a longer experience in methods of College work, will result in saving a considerable number who would have failed under the former system.

In connection with this change in the distribution of work, should be noted the increased provision that has been made during the year for instruction in History, Political Science, Philosophy, and Modern Languages. The value of such studies, as a part of the training of students in technical courses, is coming to be more widely recognized year by year throughout the educational world. While careful attention must be given to both pure and experimental science by those who are preparing for the industrial professions, experience shows that a purely technical training is in danger of becoming too narrow, unless associated with other branches of study of a kind to stimulate and broaden the range of intellectual activity. The demand of the age is for a breadth and grasp of intellectual power that shall keep pace with the enormous material advancement which the world is now witnessing. The real problem in technical education, is, accordingly, how to secure the greatest economy of time and labor in laying the foundations of a professional career, and, at the same time, to impart an education, in the older sense of the term, which shall look to the development of the man, as such. From the nature of the case, a tenchnical training, with its constant accompaniment of laboratory practice, involves more or less of the professional element and thus becomes, to a degree, true university work. The attractiveness of such work is almost certain to absorb the student's attention and to make him increasingly impatient of the careful drill necessary to a mastery of foundation studies. It is for this reason all the more important that the studies in the earlier stages of such a course should be carefully selected, properly balanced, and rigidly required. This theory involves the fact that there are certain general subjects without a fair acquaintance with which no man can be regarded as educated, even in the narrowest sense, and a knowledge of which is absolutely indispensable in enabling one to make the most extensive technical training fully available. The College has now for many years steadily pursued the line of policy thus briefly hinted at, and the continued success of our graduates furnishes most gratifying evidence of its correctness. For the last two or three years, almost every member of the graduating class has been assured of a position before taking his degree, and it has frequently happened that the heads of departments in the College had more calls for men than they could supply.

The requirements for admission to the Freshman Class are nominally the same as for the past two or three years, but it has been gratifying to note many signs of steady improvement in the quality of the preparation of candidates. We have many evidences of increasing effort on the part of preparatory schools to meet the entrance requirements of the College, and the result has been a steady strengthening of the work in our several courses, but much is still to be desired in this direction. A considerable number of students who have nominally covered the requirements for admission are found so fundamentally deficient in their knowledge of the meaning of language and of the fundamental principles of Mathematics that they are seriously handicapped in taking up College work, and the result is that a considerable part of the Freshman year is necessarily devoted to a kind of training that ought to have been secured in a preparatory school. In spite of this fact, our standard has actually been advanced, and, with continued improvement in the work of preparatory schools, it is reasonable to anticipate that, with little or no increase in the nominal requirements for admission, a foundation may be secured for a very substantial increase of the amount and quality of work done in the College.

The suggestion is sometimes heard that the College employs too large a teaching staff in proportion to the number of students, but this suggestion comes either from those who have not carefully examined the subject, or from those whose observation, or lack of observation, leads them to confound the requirements of such an Institution as this with those of a strictly literary classical College. In institutions of the latter class it is possible to lecture to one hundred or two hundred students as easily as to twenty or thirty, and with little or no apparatus, in either case. Even then, however, in subjects requiring class-room drill, there is a limit of numbers beyond which teaching cannot be effective. But, in an institution like the State College, where every course is accompanied by a large amount of laboratory training, in some form, and where instruction must be very largely individual, it is readily seen that the number of students who can be effectively taught at one time is necessarily small. About seventy-four per cent. of our students are enrolled in the Engineering courses, and it is but the simple truth to say that our own experience, supported by that of other institutions doing the same grade of work, demonstrates the immediate necessity of doubling the teaching force in those departments. The remaining twenty-six per cent. are distributed among Agriculture, Biology, Botany, Chemistry, and the general courses in History and Political Science, Modern Languages, Philisophy and Ethics, with Latin and Greek for those who elect those studies. Viewed relatively to the number of students in these courses (with the exception of Chemistry and Modern Languages) the number of instructors is sufficient to provide for a considerable increase in the size of classes, but it is to be borne in mind, first, that several of the subjects named form an integral part of all courses in the College, including the Engineering courses, and, second, that there is an increasing demand for the general, in distinction from the technical courses. If the State College of Pennsylvania is to observe either the spirit or the letter of its charter, as prescribed by the Act of Congress of 1862, it must provide a "liberal" as well as a "practical" education "in the several pursuits and professions of life." It would be a grave misfortune if the day should every come when the work of the College should be exclusively technical. Aside from the knowledge of subjects, outside of his special line which every technical student ought to acquire in his course of education, the presence of those who are pursuing other courses has a quickening and broadening influence upon the whole body which is, in itself, no mean education. Especially is this true of those subjects which teach the principles of good citizenship and the foundation of Constitutional freedom.

What has been already said with regard to the need of more instructors in the Engineering Departments is equally true in the Departments of Chemistry and of Modern Languages, including English. Nothing but the enthusiasm and energy and devotion of the great body of the teaching staff has made it possible for the College to accomplish the amount and quality of work of which we are justly proud and which the people of the State are rapidly coming to understand and appreciate. But there is no worse economy for an institution of learning than to overwork its instructors, especially in a technical institution. If they are to keep abreast with the unprecedented advances which are now being made in every department of knowledge, if they are to teach with freshness and force and enthusiasm, they must have ample time for daily recreation and especially for daily study, and this, not simply as a means of successful work in the class-room, but what is almost more important as a means of maintaining a wholesome and helpful influence upon the whole body of student life.

I might dwell at tedious and painful length upon the needs which daily present themselves to my attention, but I content myself with referring to the reports from the several Departments, copies of which have already been placed in your hands. These reports show a firmness of grasp, and a definiteness of purpose which cannot fail to command confidence, and the one fact which they most clearly and unanimously disclose is that the College has now reached a period of its history when it is of the first importance that it should have a fixed annual income. I need not dwell upon this but simply desire to call attention to it as the one thing towards which, in my judgment, the energies of the Board of Trustees should now be especially directed. In conclusion I desire to renew my expression of thanks to my associates in the Faculty for their loyal and unflagging service and to the Trustees for their unfailing support.

Respectfully submitted,
GEORGE W. ATHERTON,
President.

State College, Pa., June 12, 1900.

# I.—AGRICULTURE.

## (a) GENERAL.

To the President:

Sir:—I have the honor to present herewith the report of the Department of Agriculture for the present college year. The work and progress of the Department may for convenience be discussed under three divisions:

1. The continuation of work inaugurated many years ago;
2. The continuation and development of the Correspondence Courses in Agriculture;
3. The development and progress of Nature Study work introduced by this Department to aid the public school teachers in establishing Nature Study as a school exercise.

The work that will most naturally fall under the first division consists mostly of the prescribed work of College instruction. But few changes have been made in this work during the past year. Some additions, however, to the equipment have been secured. These consist for the most part of animals, which are used for class illustration and for the practicum work of judging. During the past year, several pure-bred Shorthorn cattle have been secured, and representatives of four breeds of fowls were imported from England. While two of these breeds were practically untried in this country, yet the results thus far obtained from them are quite promising.

As a considerable portion of the instruction given in the Course in Agriculture depends upon the equipment of the farm, the Department feels the need of better illustrative material, particularly in the Animal Industry Work. At the present time, the College is maintaining but three herds of pure bred animals, two of cattle and one of swine. It will be necessary to provide representatives of other breeds of domesticated animals if The Pennsylvania State College is to maintain instruction equal to that given at other agricultural colleges that are already supplied with this most necessary equipment. Representatives of other breeds of cattle could be conveniently accommodated with the present barn facilities.

During the past year, many letters of inquiry have been received pertaining to the Short Course in Agriculture, and graduates in this course have expressed a wish that the course may be given another year. The re-establishment of the course will undoubtedly strengthen the department, and will meet a most hearty approval by the agriculturists of the State.

At many agricultural colleges the short courses are given prominent positions and have proven to be a potent means of materially strengthening the work of the department and have brought the College in closer touch with the practical agriculturists of the State than would have been possible had the four years' course alone been given. The attempt of the Department of Agriculture of The Pennsylvania State College to keep in touch with the practical agriculturists of the State thus far has met with a liberal response, and in no direction have the efforts been more fully rewarded than in the attempts to aid the farmers by means of the Short Courses in Agriculture.

The work of the second and third divisions consists of the development of the Correspondence Courses in Agriculture and the publication of Nature Study lessons designed for the use of teachers in the public schools throughout the State. These subjects were discussed quite fully in a recent communication to the Executive Committee. The following brief summary of this communication may express fairly well the present condition and needs of the department as regards these branches of work.

During the years from 1892 to 1896, the Chautauqua Course in Agriculture offered by the College showed a marked development, a growth that met the expectations of the most sanguine. While this work was necessarily incomplete, yet it paved the way for more efficient and better work that was to follow. During 1896 and 1897, it was evident that this Course of Home Study in Agriculture was not meeting the full demands of the practical agriculturist who wished to pursue at his own home a somewhat systematic course of study. Consequently, in 1897, lessons were prepared on subjects treated of by seven books in the Chautauqua Course. These lessons were sixty-four in number and were designed to aid students who were studying these books. From the time the lessons were first offered, most of the requests from students for instruction asked that lessons be sent them. Consequently, in 1898, lessons on nine more subjects were prepared, making one hundred and twenty-six lessons in all. From this date, nearly all the students receiving instruction by correspondence made use of the lessons, less than one per cent. adhering to the Chautauqua plan of studying the book and taking examination on the whole book when finished. During the summer of 1899, lessons were prepared on four more subjects, making a total of twenty subjects, on which one hundred and fifty-one lessons have been prepared.

Aside from sending circulars each year to former Chautauqua students, very little advertising has been done, yet, during the past year more registrations of students who are actually taking work in the courses have been made than ever before. Lessons have been sent to nearly eight hundred students. In order that records may be kept of each student, and without confusion, it has been necessary to adopt a somewhat elaborate system of bookkeeping, which adds materially to the labors of the office of the Superintendent. The work of grading the lessons is a heavy task and canot be continued on the present basis of membership in the Correspondence Courses without seriously interfering with the regular college work, unless additional assistance is provided. The many letters received from students in these courses commending most heartily the work the College is doing for Agriculture throughout the State and the number of students applying for enrollment warrant us in believing that thousands would enroll if they but knew of the advantages that the College is offering. The development of the Correspondence Courses to their present state of efficiency has been accomplished in part by effort that could profitably have been given to the regular College instruction. To pursue this method further will undoubtedly interfere still more with the efficiency of the prescribed College work.

For a number of years it has been well known that efforts were being made by agricultural colleges of the various states in the Union to reach the pupils in the public schools, believing that the greatest good to agriculture would only come by improving the source from which all agriculturists primarily receive instruction—the public school. Instead of following the methods adopted by other States in sending out to the teachers of public schools leaflets simply to interest the pupils of various ages, or of all ages, the College has adopted the plan of giving a systematic course of instruction to the teachers, that is designed not only to aid them in interesting the pupils but also to cultivate the pupils' powers of observation and develop in them, if possible, a greater love of nature. In order to carry out this plan, a few lessons have been written and printed in Nature Study on Insect Life and Animal Life. Other lessons are in the course of preparation. The available funds for maintaining the Correspondence Courses and Nature Study work at the opening of the present college year did not warrant the placing of Nature Study lessons before all the teachers of the State. Consequently, a small edition was printed and copies sent out to a few teachers in various parts of the State. Probably not more than ten or twelve per cent. of the teachers have received Nature Study lessons. Cornell University claims to be in touch with ninety per cent. of the teachers in New York State through the Nature Study lessons. As there are about twenty-nine thousand teachers employed in New York State at one time, Cornell University reaches about twenty-six thousand teachers, while State College, at the present time, has been able to reach something less than four thousand teachers of the public schools in Pennsylvania. From the reception that the Nature Study lessons have received in the hands of the various classes of educators, from the Superintendent of Public Instruction to the teacher in the country school, assurance is given that an equally large percentage of teachers in Pennsylvania would avail themselves of the Nature Study work were the same opportunity offered them as has been offered to the teachers in New York State.

Th School of Agriculture has in contemplation the issuing of three courses of Nature Study, namely, Insect Life, Animal Life and Plant Life, to be followed by courses of lessons somewhat more advanced, so that the instruction in Nature Study will not end with the lessons of the primary courses which are now being prepared and sent out.

In order to carry on the Nature Study work and that of the Correspondence Courses to meet the demands of the students and teachers who have learned of the advantages offered by the College, aid is rquired to relieve the Superintendent of the increased labors due to the Correspondence Courses and Nature Study work. Such aid, to be efficient, should not be lower in grade than that expected of Assistant Professors. A person, in order to grade properly the examination papers and attend to the correspondence required by errors in the papers, questions asked, etc., must be thoroughly familiar with the whole subject-matter of the lessons, both from theoretical and practical standpoints. As the lessons in the Correspondence Courses have largely to do with practical agriculturalists, experience in practical agriculture oftentimes is quite as important as scientific training. For this reason, recent graduates of agricultural institutions are not fitted to perform this work without closer supervision than the Superintendent is able to give.

If the Correspondence Courses are to be somewhat extended, as the records for the past year strongly indicate the growth that would take place providing opportunity were offered to the people of Pennsylvania, and the Nature Study work extended to fifty per cent. of the teachers of Pennsylvania, allowing each teacher only ten or twelve lessons per year, at least fifteen thousand dollars would be required for two years to meet the expenses of printing, postage, stationery, salaries, and other necessary expenditures. This estimate has been carefully made from the record of expenses already incurred in the Nature Study and Correspondence Courses and may be considered conservative. It would appear extremely so when we consider that Cornell University annually appropriates one-half of the annual Nixon fund appropriation of thirty-five thousand dollars for the maintenance of Nature Study and extension work, and a considerable portion of the remainder is used for purposes closely relating to it.

All of which is most respectfully submitted.

G. C. WATSON,
Professor of Agriculture and Superintendent of Correspondence Courses.

State College, Pa., May 5, 1900.

## (b) AGRICULTURAL CHEMISTRY.

To the President:

Sir: I have the honor to submit herewith a brief report of the work of the Department of Agricultural Chemistry, of the College, and of the Chemical Laboratory of the Experiment Station, for the year ending June, 1900.

Relative to the Department of Agricultural Chemistry of the College: The scheduled lectures for the Sophomore Class were rearranged in order that my time might be set free for attendance as a representative of the College at the Farmers' Institutes held during the Winter months. During the Fall, I delivered to a section of the Senior Class a series of lectures on the Machinery and Processes of Fertilizer Manufacture, and a brief series upon the Chemistry and Analysis of Milk and Its Products.

A course of laboratory instruction in selected methods for the analysis of fats and oils, soaps, starches and flours, sugar-house products, vinegar and tanning materials was conducted in accordance with my directions by Mr. C. A. Browne, Jr., to whose most efficient work in this connection much praise is due. Mr. Browne also conducted a course of study on selected subjects relating to Rural Technology based upon Sadtler's Industrial Chemistry.

During the Spring term, I delivered a course of lectures forming the first portion of the general course in Agricultural Chemistry to the Freshmen Class; practicum exercises have been carefully prepared to correspond with the lectures and have been carried out from day to day by the class under Mr. Browne's supervision.

With the re-arrangement of subjects accompanying the division of the College year into two instead of three terms, and the introduction of Organic Chemistry as a part of the General Course in Chemistry of the Sophomore Class, a better sequence in presentation of the topics of the General Course in Agricultural Chemistry has become possible, the outlines of Organic Chemistry with which the latter course has heretofore begun being now omitted, the practicum hitherto devoted to a study of plant substances postponed to a later term, and, in its place, a practicum upon certain points in the chemical relations of the plant to the air substituted.

Since Agriculture is less fitted, from the scope of its subject matter and the variability of its conditions, than most occupations for the successful application of empirical rules, the professional training of an agricultural student should not only equip him with a fund of accurate, up-to-date information, systematically arranged, upon important farm topics and their related sciences, but should also give him facility in the application of those two most potent mental instruments for the discovery of truth—observation and experiment.

The lectures and practicums in Agricultural Chemistry, both because the subject is especially adapted for the inculcation of methods of observation and experiment and because it is the first of the technical subjects pursued by students in the Agricultural course, are carefully devised and conducted for the purpose of developing the student's powers in these directions. The work of this term has included quantitative studies of the ultimate composition of plants, their moisture content, the composition of the air, especially as regards oxygen, ozone, nitrogen compounds and carbonic acid, the loss of water by the plant through transpiration, the absorption of oxygen and the evolution of carbonic acid through respiration, the taking up of carbonic acid, giving off of oxygen and deposition of starch during assimilation, and the influence of climatic conditions upon the rate at which these processes are carried on.

The introduction at the end of the Sophomore year of a Summer School period of 100 hours for practice in agricultural analysis, will provide a far more satisfactory course in this subject than has heretofore been possible in the brief, broken periods allotted for the purpose.

Concerning the equipment of the work, I would respectfully urge, as in preceding years, the need for satisfactory lecture rooms and laboratory, and for such appropriations as will provide for the purchase of several microscopes fitted for demonstration, and slides and other much needed material, and for the preparation of charts to accompany the lectures. Such additional equipment would enable the classes to work with less hindrance and cover the ground more perfectly than is now possible.

In addition to the work of the College course, mention may be made in this connection, of a brief course of lectures upon the Chemistry of Cookery which the writer is preparing for the Correspondence Courses.

Relative to the work of the Chemical Laboratory of the Experiment Station: There have been some changes in the personnel of my force of Assistants during the year: Upon the return of M. E. McDonnell, Ph. D., from his leave of absence for study abroad, the connection of Mr. A. N. Diehl as Assistant Chemist to the Station in his stead, terminated. In November, Dr. McDonnell resigned his position to accept one as bacteriologist to the Pennsylvania Railroad Company.

In March, 1900, Mr. Harry Way, Fellow in Agricultural Chemistry, resigned to enter a business position as farm manager. Mr. J. A. Fries served on special duty with the Director during the year.

As in late years preceding, the most prominent part of the laboratory work has been that connected with the State fertilizer control. For the season ending July, 1899, there were analyzed in this connection four hundred and three samples; and for the Fall of 1899, three hundred and thirteen; in addition to the care of the chemical work and valuations for which, as in past years, the Chemist was responsible, the duty of preparing the Department bulletins presenting the work of the Control, this year devolved upon me. To Mr. C. A. Browne, Jr., for the determination of potash and chlorin; Mr. M. S. McDowell, for those of nitrogen and the care of the samples; Mr. C. W. Norris, for those of soluble and insoluble phosphoric acid; to Messrs. A. N. Diehl and C. P. Beistle for those of moisture and total phosphoric acid, my thanks are due for their industry and care, and especially to Mr. McDowell and Miss Garner for their aid in caring for the records and correspondence and in preparing the Bulletins.

There were also analyzed a number of samples for the State Dairy and Food Commissioner.

Among the items of work of investigation carried on during the year, I may mention the following:

1. A study of the mechanical and chemical composition of three of the best known bench-soils for roses by the writer and Mr. C. P. Beistle.
2. A study of dried distillery waste, by Mr. C. A. Browne, Jr.
3. A continuation of the study of the changes which cider undergoes in its conversion into vinegar, by Mr. Browne.
4. The completion of the study of the chemical and mechanical effects wrought by application of lime to a number of typical Pennsylvania soils—a study undertaken, by permission, on behalf of the State Department of Agriculture: In this connection the writer was assisted during the year by Messrs. McDowell, Norris and Beistle.
5. A study, under similar auspices, upon the chemical composition of the apple and its products by Mr. Browne.
6. A chemical study of the humus in the soil of certain of the plots of the General Fertilizer Series of this Station as affected by the system of manuring to which they have been subjected—a thesis for the baccalaureate degree by Mr. Enos Hess, under supervision of the writer.
7. Study of the methods of Cattle-food analysis, performed by Mr. Browne, as Associate Reporter upon Cattle Foods for the Association of Official Agricultural Chemists, with Mr. Beistle.

Some interesting results were obtained by Mr. Way in a study of the Chemistry of the "Crude Fiber," of several forage materials, but he was obliged to leave his work incomplete.

Other investigations are in progress: By Mr. Browne, upon the composition of the fiber of cattle-foods; by Mr. McDowwell, upon certain constituents of the urine of domestic animals, especially the organic, non-nitrogenous matter, and by Mr. Beistle, upon the estimation of sulphur and phosphorus in organic materials concerned in calorimeter work.

In addition, the writer has continued the scientific direction of the tobacco experiments begun in 1893. Since June 1, last, the State Department of Agriculture has had no connection with that work, and it has been continued through the co-operation of the Station and the representatives of the Lancaster County and Bradford County Tobacco Societies. At Donegal, under the local supervision of Mr. M. L. Greider, the system of experiment begun in 1898 was continued; at Wysox, under the supervision of the Hon. Louis Piollet, the system of experiments begun in 1897 was continued. In addition to the work directly involved by the continuation of the field trials, the quality of the sweated leaf from the crops of 1893, 1894, 1895 and 1896 was carefully tested with the co-operation of expert tobacco judges. The writer's thanks are especially due in this connection to Messrs. Greider and Piollet for their interested and intelligent co-operation.

As the principal items in the bibliographic record for the laboratory during the past year, the following may be mentioned:

By the writer:

Bulletin No. 51, Pennsylvania Department of Agriculture: Analysis of Commercial fertilizers, January-August, 1899, pages 69.

Pennsylvania Department of Agriculture: Report of Fertilizer Experiments with Tobacco (Summary).

Bulletin No. 49, The Pennsylvania State College Agricultural Experiment Station. Report of Fertilizer Experiments with Tobacco (Summary).

Report of The Pennsylvania State College Agricultural Experiment Station (in press). Comprehensive Report of Yields of Tobacco from Fertilizer Experiments, 1893-1897.

Bulletin No. 54., Pennsylvania Department of Agriculture: Tabulated Analyses of Commercial Fertilizers, January-December, 1899.

Bulletin No. 48, The Pennsylvania State College Agricultural Experiment Station: Composition of the Winter and Spring Wheat Brans Bought in Pennsylvania Markets: with W. A. Hutchison.

Bulletin No. 50, The Pennsylvania State College Agricultural Experiment Station: Distillery Waste (with C. A. Browne, Jr.); Miscellaneous Analyses of Cattle Foods.

The Chemical Composition of Rose Soils: with C. P. Beistle. Printed in American Gardening.

Bulletin No. 61, Pennsylvania Department of Agriculture: The Use of Lime in Pennsylvania Soils: Appendix (with C. A. Browne, Jr.); Compilation of Analyses of Pennsylvania Limestones. (In Press.)

By C. A. Browne, Jr.:

A Contribution to the Chemistry of Butter Fat:
I. The Physical and Chemical Constants of Butter Fat;
II. The Chemical Composition of Butter Fat;
III. The Chemistry of Rancidity in Butter Fat, (Published as contribution from this Laboratory in the Journal of the American Chemical Society, Vol. 21, 612-633; 807-827; 975-944.)

Bulletin No. 58, Pennsylvania Department of Agriculture: A Chemical Study of the Apple and Its Products.

By C. W. Norris:

Report upon Meteorological Observations for 1897 and 1898, at State College, Pa.: For Annual Report of the Experiment Station for 1899; prepared under direction of the Chemist.

By M. E. McDonnell:

In this connection mention should also be made of the valuable inaugural dissertation presented by Dr. McDonnell to the Philosophical Faculty of the University of Kiel, in 1899, for his Doctor's degree, upon the subject of Lactic Acid Bacteria.

The demands upon my time made by interests in whose development the College and Station are in co-operation have been fully as large as usual. In addition to several Summer institutes which I attended, I was present as the detail from the College at nearly all of the Winter Institutes in the Northern section of the State, consecutively, from November 29th, 1899, to February 17th, 1900. Mr. M. S. McDowell was also detailed for attendance at a few institutes.

In conclusion, permit me to express my appreciation of the consideration and cordial approval on your part by which the performance of much of the work aforementioned has been made possible.

Very respectfully,
WILLIAM FREAR,
Professor of Agricultural Chemistry.

State College, Pa., May 22, 1900.

## (c) AGRICULTURAL EXPERIMENT STATION.

To the President:

Sir: I have the honor to submit the following report upon the work of the Agricultural Experiment Station and of the School of Agriculture for the year 1899-1900.

### The Experiment Station.

No material changes in the activity of the Experiment Station have occurred within the past year, but the work along the lines of experiment previously undertaken has been continued, although with some interruptions arising from the increasing demands of the work of instruction, both at the College and throughout the State at large through the medium of the Correspondence Courses and the Farmers' Institutes.

Animal Nutrition. The construction of the respiration calorimeter in co-operation with the United States Department of Agriculture has been continued during the year and the apparatus is now approaching completion. The construction of a special building for this apparatus, which was authorized by the Trustees last year, was somewhat delayed on account of necessary changes in the plans, but the building was completed in November, since which time work has been in progress upon the apparatus itself. The building is a substantial, one-story structure, 35x57 feet outside, of red Mill Hall brick, with slate roof. The interior walls are all of brick, and these, with a steel ceiling, render the building, to all intents and purposes, fire-proof. Special care was taken to make the interior of the building as little subject to the changes of external temperature as practicable, the brick walls being double and containing a 4-inch air-space, and all windows being provided with storm sash. Even during the coldest weather of last winter, a very small amount of steam sufficed to keep the building at a comfortable temperature.

The purpose of the apparatus is to determine the products given off in the respiration of an animal and also the amount of heat produced during the same time. By comparing these with the composition and heat-value of the food consumed, it will be possible to determine with a high degree of accuracy the exact use which is made by the animal of the various elements of its food and how the percentage utilization is affected by various conditions. The apparatus consists essentially of an air-tight box of sheet copper through which is led a current of air whose volume and composition both before and after passing through the box are known. The animal under experiment is placed in this box and the products of its respiration are determined in a fractional part of the air current just mentioned. In addition to this, a current of cold water, passing through a series of copper pipes in the box, serves to carry away the heat given off by the animal, the amount of which is measured by the weight of the water and its increase in temperature. The remainder of the apparatus consists of ingenious and somewhat complicated devices for preventing any loss of heat through the walls of the chamber or in the air current. All these things involve a vast amount of detail and the construction of the apparatus has necessarily appeared somewhat slow. It is now anticipated, however, that test experiments can be made with it at an early date.

During the year, an experiment pertaining to the economy of different methods of watering and handling fattening steers has been carried out, in co-operation with the State Department of Agriculture, by the Agriculturist of the Station. This experiment has been conducted at the College barn in a most satisfactory manner. As two or more carloads of steers are annually fattened on the College farm, it will be desirable to repeat this experiment on a larger scale in following years and to solve, if possible, some of the practical questions relating to the feeding of fattening animals which now confront the farmers who depend upon fattening steers each year to maintain the fertility of their farms.

Agricultural Chemistry. The chemical work of the past year has been to a large extent similar to that of previous years. The two main divisions of this work are the work of fertilizer and food analysis for the State Department of Agriculture and the check work required by our own investigations in the field and stable. In addition, a considerable number of samples of various sorts have been received for analysis.

As in preceding years, the work connected with the State Fertilizer Control has been the most prominent part of the chemical work. For the season ending July, 1899, there were analyzed in this connection four hundred and three (403) samples and in the fall of 1899 three hundred and thirteen (313). In addition to the care of the chemical work and valuations, for which, as in past years, the Chemist of the Station was responsible, the Chemist was also called upon this year to prepare the Department bulletins presenting the results of the work.

In addition to the routine work above noted, a considerable amount of work of investigation has been carried on during the year under the direction of the Chemist of the Station, including a study of the mechanical and chemical composition of three bench soils for roses; a study of dried distillery waste; a chemical study of the humus in the soil of certain of the plots of the general fertilizer series; and a study of methods of cattlefood analysis for the Association of Official Agricultural Chemists.

A considerable amount of chemical work has also been undertaken on behalf of the State Department of Agriculture by members of the Station force, including a study of the chemical and mechanical effects of lime upon typical Pennsylvania soils; a study of the chemical composition of the apple and its products; and a study of the changes which cider undergoes in its conversion into vinegar. Investigations are also in progress upon the composition of the crude fiber of cattle foods, upon certain constituents of the urine of the domestic animals, and upon the use of the bomb calorimeter for the determination of sulphur and phosphorus in organic materials.

Field Experiments. The work in this Department during the past year, under the charge of the Agriculturist, has consisted chiefly in carrying out the plans of experiments that have been in progress for a number of years. While experiments designed to test the efficiency of new methods and the utility of comparatively new plants have not been ignored, yet the larger share of our attention has been given to carrying on the somewhat extensive fertilizer tests which have been in progress for more than nineteen years and the variety tests of wheat, oats and potatoes. The fertilizer tests include each year thirty-six plots each of four crops—wheat, grass, corn and oats—the plots of each crop receiving twenty-four different kinds of treatment as regards the application of fertilizers. As this experiment has now been conducted through nineteen years, or four complete rotations of four years each, the data obtained from the average yields of the various plots furnish most interesting information and will be the subjects of forth-coming bulletins.

The variety tests of wheat, oats and potatoes have furnished interesting results, showing that, under uniformly good conditions, the yield depends more largely upon the kind and quality of the seed than is generally supposed by the practical agriculturists of the State.

For three years, tests have been made of seeding land to crimson clover. Heretofore, the Station has been called upon to advise the farmers as to the best time of sowing this seed without having made practical experiment. These tests have each year given corroborative and decided results.

Various soiling crops have been grown with a view of comparing their feeding value, as well as to test the ease of production on the somewhat heavy clay soil of the Experiment Station farm, which fairly represents a large proportion of the soil of central and southeastern Pennsylvania.

The field experiments with fertilizers upon tobacco in Lancaster and Bradford counties have been continued from previous years in charge of the Chemist of the Station. A partial report was made last year upon the field results and a similar report upon other phases of the work is in preparation.

Dairying. A large share of the time of the Dairy Department has been taken up with the work of instruction and it has not been found practicable to initiate any extensive researches, but incidentally, in connection with the work of the Dairy School, a number of tests of separators have been made. A series of experiments has also been begun upon the question of moisture in butter in the hope of getting more light upon the influence of various conditions in determining this important factor, and some experiments upon the manufacture of dried curd are planned.

Horticulture. In our trial grounds we have maintained the plantations of the several small fruits, testing the many varieties which are sent to us from time to time by our patrons. An experiment upon whole and piece root apple grafts is in progress and the trees are making satisfactory growth, but a long period of years will be required to observe any permanent effects of the two systems of propagation. An experiment in Ginseng culture is progressing to our satisfaction, and in a few years more the young roots planted will have reached maturity in our lattice house.

Considerable alarm has been aroused by the growing prevalence in our State of the disease of nursery trees known as crown gall. Our efforts in the past two years to find a remedy have not yet been successful on account of the difficulty of causing the disease to develop in our soil, but experiments have now been inaugurated upon a nursery where infected soil is known to exist, and various remedies are being tried there.

Publications. The following bulletins have been issued during the year: No. 46, Variety Tests of Wheat; No. 47, Tests of the Sugar Beet in Pennsylvania; No. 48, Winter vs. Spring Wheat Bran; No. 49, Field Fertilizer Experiments on Tobacco; No. 50, Distillery Waste, Miscellaneaus Cattle Food Analyses. As noted in the last Report, the present plan of publication contemplates comparatively brief popular bulletins, freely distributed, while the Annual Report, of which only a limited edition is printed by the State, is intended to be somewhat more technical in character and to constitute the place of ultimate record for the results of experiments.

The mailing list of the Station has been revised during the year. With Bulletin No. 46, a request was sent out for acknowledgment from those desiring subsequent bulletins. Approximately 8,000 were thus acknowledged and the names of those responding have been entered on the new mailing list.

The correspondence of the Station during the year has been quite extensive, covering the usual variety of subjects. In all approximately 5,000 letters have been received during the year.

Personnel. But few changes have occurred during the year. Dr. M. E. McDonnell, who had been connected with the Station since 1893, resigned October 1st to accept a position as Bacteriologist of the Pennsylvania Railroad. Mr. A. N. Diehl terminated his engagement as Assistant Chemist at the close of last year, and the Fellowships in Agricultural Chemistry and Dairy Husbandry were filled by the appointment respectively of Messrs. H. O. Way and W. F. Wood, graduates in the class of 1899. Both these gentlemen resigned during the year, however, to accept more lucrative positions on large farms.

Library. The library of the Station is being catalogued in accordance with the modified Dewey system as proposed by the Librarian of the United States Department of Agriculture. It now contains about 1,300 volumes, consisting largely of technical periodicals, particularly foreign, and of the reports and bulletins of other Stations.

Needs of the Station. The farm equipment of the Station is in urgent need of some additions and improvements to bring it up to the standard of the best farm practice, which it ought unquestionably to maintain. During the past year, a stave silo of a capacity of about 110 tons has been added to our farm equipment. We should, however, have a second one in order to furnish a liberal supply of silage to our dairy herd. In addition to this, there is urgent need for a suitable implement and tool house, a piggery with facilities for experimental work, and a poultry house with accommodations for incubators and brooders. The barn yard, which is now partly roofed, should be brought entirely under roof, and the cow stable should be re-arranged and properly floored to prevent waste of manure. For the proper development of the horticultural work of the Station, a green house or houses especially for experimental work is also an indispensable requisite.

As I have pointed out in previous reports, the State makes no appropriation for the current work of the Station and during the thirteen years since the establishment of the Station has appropriated but $19,000 for equipment. Other States inferior in wealth and resources to Pennsylvania have, on the other hand, liberally supplemented the Hatch fund by State appropriations and as a consequence their Stations are carrying on a range and variety of work which is impossible for us under present conditions. This fact I believe to be worthy the serious attention of the Board of Trustees and of the State. Even a very moderate addition to the annual income of the Station would make a vast difference in the amount of work which it would be possible to undertake. We have men competent to carry on examinations and researches which would be of great benefit to the agriculture of the Commonwealth, but at present we lack the means to make the most efficient use of these men. As a measure of true economy, they should be relieved, as far as possible, from the mechanical and clerical details of their work which now consumes too much of their energy and be abundantly furnished with all the apparatus and equipment necessary for effective work.

## The School of Agriculture.

The Agricultural Courses. The small appropriation which the State found it possible to make in 1899 for the support of the work of the College, and the increasing demand for Institute work on the part of members of the School of Agriculture, combined to render necessary some contraction of the work. Accordingly, after careful consideration of the whole situation, it was decided to discontinue temporarily the Short Course in Agriculture and the Cheese-Making Course, these being apparently the ones for which there was the least popular demand. This action, while it appeared unavoidable under the circumstances, was exceedingly unfortunate. Two years before, it was found necessary to change the date of the Short Course, with the result of a comparatively small attendance; the following year it was held at the usual time, but the change of the year before reacted unfavorably upon it, and but few registered. Following this comes the suspension of the Course for the present year. Similarly the Cheese-Making Course, which had but just been established and which had not had time to become known to the cheesmakers of the State, was suspended and the work which had been expended on it was practically lost.

I desire to call special attention at this time to the great importance of re-establishing and enlarging the Short Course. The experience of other States has demonstrated beyond question that the most urgent present demand is for agricultural education of what might be called high school or secondary grade, and in those states where this demand has been liberally and systematically met, schools of agriculture have been developed which are doing most valuable work for the agricultural community. I need only refer to the Short Courses of States like Wisconsin and particularly to the School of Agriculture of Minnesota. It seems to me exceedingly important that in our own State the increasing demand for agricultural education should be met by the provision of suitable quarters and supplies for such a school of Agriculture. It should be liberally supplied with all necessary means of demonstration and illustration and should offer a systematic course extending through the winter months of two or three successive years, but so arranged that even a single winter's work would be of value to the student. Such a School I cannot doubt would have the effect of greatly stimulating agricultural prosperity in our Commonwealth and of increasing the respect accorded the farmer by helping to render his calling an intellectual occupation.

The demand for Institute work also rendered necessary a transposition of subjects in the collegiate course and a consolidation of classes. While the call for outside work was such as to seem to warrant this, its effects were nevertheless bad, and such action should be avoided in the future. It should also be noted that this change affected students taking special work in agriculture by limiting to a considerable degree the range of choice afforded them.

The Creamery Course has continued to prosper as in years past, the number of applicants being nearly double what could be accommodated in our limited quarters. It seems self-evident that, since this demand has continued from year to year without being stimulated by advertising, some adequate provision should be made immediately, by the erection and equipment of a suitable dairy building, for providing that special training which the dairy interests of the State demand.

Extension Work. The various forms of extension work in agriculture, which the College is carrying on, have shown very remarkable and gratifying growth during the past year. The Correspondence Courses, notwithstanding the fact that no effort has been made to push them, have shown a steady growth. About two hundred new students have been enrolled during the year, and the total number doing active work in the Correspondence Courses now amounts to nearly eight hundred.

The lessons in Nature Study, designed for teachers in the public schools, have met with a much warmer reception than was anticipated. Ten lessons have been prepared and printed and of these between three and four thousand copies have been distributed in the public schools. Many expressions of interest and appreciation have been received from teachers and we cannot doubt that the work thus begun in a small way is meeting a conscious want. It should be possible largely to increase the amount and scope of this work.

During the past year four members of the School were detailed for Institute work during the whole season, while the assignment to the fifth section of institute workers was provided for by the detail of several different members of the School for short periods. The importance of thus bringing members of the School and Station in direct contact with the farming communities of the State, and conversely of bringing to these communities in a simple, practical way the results of the investigations made a the Station, cannot readily be overestimated. The work of the farmers' institutes, while primarily practical in its character, is necessarily coming to depend more and more upon the results of the work of the Stations and Colleges and it cannot in this day be prosecuted effectively without the aid of scientifically trained men. From all these points of view, it is exceedingly important that the College should be able to carry on its proper share of this work, without detriment to its special functions of investigation and teaching.

In brief, then, there is every reason for a liberal support of the various branches of extension work. The work is important, not only because of the information which it brings to the farmer, but because it helps to fit him to appreciate and utilize the results of Experiment Station work as presented in bulletins and reports and conversely relieves the Experiment Station of the demand for the publication of bulletins of information, etc., and leaves it free to carry on its proper office of investigation and research.

Needs of the Work. The College is the recognized and only agency of the State for systematic instruction in agriculture and as such has a very wide field of work. This field it has endeavored to cultivate as efficiently as possible with the means at its disposal. It rests with the agriculturists of the State to say whether the work on its present limited scale is adequate, or whether it shall be so expanded as to be commensurate with the importance of agriculture and the dignity of the Commonwealth. Such an expansion, to meet what seems to be present demands on the part of the people, would involve

First, Adequate quarters and equipment for secondary instruction in agriculture, including a School of Agriculture devoted to the practicable instruction of farmers' boys and girls in the principles of natural science and their special applications to farming, and special courses in dairying, and possibly for other branches.

Second, Liberal support for the various phases of extension work, including the Correspondence Courses, Nature Study for teachers, and the attendance upon Farmers' Institutes.

In conclusion, I desire gratefully to acknowledge the uniform and cordial support which has been accorded to the work in agriculture by yourself and by the Board of Trustees, and the constant effort which has been made, amid the perplexities arising from insufficient income, to maintain that work at the highest possible degree of efficiency.

Respectfully submitted,
H. P. ARMSBY,
Director and Dean.

State College, Pa., June 12, 1900.

## II.—BIOLOGY.

To the President:

Sir:—In the Report of 1896, Dr. Fernald carefully outlined the aim of the Department in Biology and in the '97 report called attention to the work of the Senior Class in Entomology as related economically to agriculture—a relation, the value of which, he was able the following year successfully to demonstrate to the State at large. In the same report he gave a list of the improvements for that year. To say that there have been no improvements since might leave the impression of a stand-still in the Department. This is not true in any but a financial sense. Even our small appropriation was cut off last year and it has been rather hard to make the practicum dues of $2.00 per term pay all laboratory expenses. This would have been an impossibility had not material been laid by during the years of plenty—that is, comparative plenty—as against this time of famine.

Dr. Fernald had so ably carried on the work of the Department ever since it has been a Department, that it has seemed best to continue his methods, which my experience as Instructor under him last year made it possible for me to do. I should like to call the attention of the Trustees to this Department especially, as it has been very markedly brought before the public in the past few days by the action of the representatives of the Agricultural Societies of Pennsylvania in their resolution to attempt to have State legislation for Nature Study in the public schools. There have been years when there were no graduates in Biology. This year there are three and unless something happens, there will be graduates for the next four years as we have students in each college class. A graduate, of course, means much extra work, and in no department is more time needed for the preparation both of desk and laboratory material. One person can do it and has done it, but no one person can ever hope to make it the interesting subject it should be in college and through the State. Many of the leaflets for the Correspondence Course must come from this Department and that means hours of careful consideration and work, for, to receive recognition, they must not be hurried productions. Hitherto, with few exceptions, our graduates have entered the medical profession, but now with this new field of Nature Study in the public schools, we should be able to offer the State very proficient teachers, for Nature Study, simple as it may seem, should only be taught by one who thoroughly understands the subject; better not be taught at all than have such erroneous ideas inculcated as have been in past years. The fact that a student graduating in Chemistry or Engineering secures a good position, is one of the chief reasons why these courses number so many students. Were this Department to offer similar inducements in the way of good positions for experienced teachers there would be more of an influx. And there is a demand for a science teacher if we are only ready to meet it. Working towards this and with Economic Zoology gradually attaining such prominence and importance relative to agriculture, it seems as though this should be one of the greatest departments in State College, as it is in Cornell and other State Institutions. With the new system of electives we are increasing the opportunities for specialization along several different lines and in courses outside of our own, and these opportunities will demand more of a teaching force and more equipment if they are to remain permanent. A fresh water aquarium, even though small, should be in every zoological laboratory and some place to keep other animals alive while observations on their habits, etc., are being made. Zoology is no longer a cramming of students' minds with technical names, but teaching them to use their eyes and deduce ideas as to habits, structure, etc. This has been recognized by Harvard, Yale, Chicago University, Cornell, in connection with all of which are summer schools for Nature Study or marine laboratories. It is surprising, in the face of financial handicaps, what successful results have been accomplished in biological work here. Our course in zoology ranks with that of Harvard, our work in vertebrate embryology is more careful than the corresponding work at many medical schools; it is not necessary to speak of Entomology for it is well known what credit Dr. Fernald brought to the Department during his year as Economic Zoologist of the State. It is working against odds, however, to keep up this record with thirty-three hours of actual class work per week and an impossibility under such conditions to devote any time to outside lecturing and writing, which will do more than anything else to bring us into repute with the schools and people of Pennsylvania. This science is growing so rapidly each year that we must grow, too, if we wish to keep pace with other institutions and do the high grade of work hitherto credited to us. The complaint comes from every department of lack of funds, but when it is realized that there is not a cent for this work while another department thinks itself handicapped with seven thousand per year for running expenses, and when it is realized how intimately this is associated with the losses to crops due to injurious insects, etc., it is a matter for importunity. With a larger laboratory and more equipment, I do not hesitate to say we could show a number of students exceeding even our most sanguine expectations, for this is a practical, not a theoretical course, and is coming to be recognized as such more fully every day.

Respectfully submitted,
ELIZABETH B. MEEK,
Instructor in Zoology.

State College, Pennsylvania, June 6, 1900.

# III.—BOTANY AND HORTICULTURE.

To the President:

Sir:—The affairs of the Department of Botany and Horticulture have been administered as in previous years with little to call for special mention or report. For your information and that of the Board of Trustees, I may be permitted briefly to rehearse the main features of our work and to comment upon them. While there have been no graduates of the regular courses of the College taking work in this department, there have been during the year several students who by virtue of their age and general attainments have been practically "advanced," in spite of the fact that their work has been chiefly with the undergraduate classes. I speak of the matter because of their uniformly excellent, in some cases, superior, scholarship, and hence the beneficial effect which they have upon other students: Having a distinct purpose, they put into their work a commendable degree of thought and diligence which has a salutary effect upon their associates. On the other hand, young men often come and take a three months' course of practical work of some particular kind, together with a modicum of class room instruction, and are duly entered, enrolled, and eventually given a certificate; often they pass in the outside world as our graduates. There may be noted also a slight increase in the number of special students who come for a year or longer to study the more practical subjects and such as their attainments qualify them to pursue. Under these conditions such pupils are generally quite satisfactory and we need not fear any lowering of our standards or interference with the progress of those who are taking a full four years' course leading to a degree. The number of students in the respective subjects has been slightly in excess of previous years, but the indications now are that for the coming year it will be somewhat smaller. Relatively small numbers in this, and more so even in some of the other College departments, we must expect so long as current notions of education are dominated by the idea of lucrative employment at its close. This causes many, even though they may have a natural bent in a particular direction, to abandon it and yield to the superior solicitations of that which promises immediate support.

With the prospective change in our school year from three sessions to two there have been some changes in the courses of study, chiefly of adaptation and distribution of subjects, and I have taken the opportunity to change somewhat the method of botanical instruction so as to be more nearly in accord with modern ideas. Methods in class room and laboratory vary with increasing knowledge and with pedagogical ideas. I have been slow to introduce any innovations until I have felt satisfied that they were meritorious and necessary and, moreover, fitted for our conditions and the grade of work which we should do. Enthusiasts in particular sciences are very prone to advocate the use of methods and matter which are not properly fitted for undergraduates, but belong to university work. In the main we have been in substantial accord with the best practice elsewhere in that we make a great deal of practical work, and depend largely upon our illustrations and laboratory demonstrations. Imperfectness of preparation of our students and immaturity of mind are the principal difficulties encountered, and have served to check any tendency to introduce and employ a higher grade of work. The new arrangement in two sessions, moreover, will give opportunity for adjustment of particular topics to the time of year best fitted for their consideration, a matter of considerable importance in botanical and horticultural study, which I have long desired.

In addition to the general method pursued in the primary and fundamental botanical instruction which underlies all practice in agriculture and other arts, I feel constrained to call attention to what we are doing in such fields as forestry and horticulture which are but special developments along particular lines. Upon the recent establishment of schools of forestry in two of our great universities there has been much favorable comment and some surprise exhibited that nothing of the kind has been done before, and that, heretofore there has been no opportunity for American students to obtain any instruction in this subject. While we have no department of forestry in this institution, still less a school of that name, we have for some years given a course of twenty-five lectures and have regularly advertised and explained the same in our published catalogue. Save for a brief statement of commendation by the State Commissioner of Forestry, who has some personal knowledge of the institution, the writer has never seen any reference to it whatever, and apparently it is not known that we give instruction of this kind. The following is a synopsis of this course:

I. Definition and general outline. The origin and growth of Forestry in Europe. The forest system in Germany, France and other countries.

II. North America, the forest continent. Reasons why but little attention has been given to maintaining forests. The forester and the lumberman.

III. The natural means of conserving or reproducing forests by seed. "Mother" trees. Methods of cutting to permit seeding.

IV. Seeding by artificial means. Seeding under different conditions. Raising seedlings for transplanting.

V. Tree planting under different conditions. Examples of artificial plantations.

VI. Propagation by cuttings. Sprout or coppice growth.

VII. General management and care of forests in order to provide for continued productiveness. Principles of thinning and cutting.

VIII. Conditions which favor trunk development. Number of trees per acre. Yearly accretion. Relation of volume increment to age. Time of maximum production.

IX. Time of most profitable cutting as related to size and age. Practical examples of management upon these principles.

X. Dangers to which forests are subject. Crude public opinion. Domestic animals.

XI. Forest fires. Fire laws. Fire prevention.

XII. Insect injury. Fungus injury.

XIII. Character of forests as related to latitude and climate. Foreign-American species.

XIV. Coniferous trees—Pines.

XV. Coniferous trees—Spruces, Firs.

XVI. Coniferous trees—Cedars, Cypresses.

XVII. Deciduous trees—Oaks, Beech, Chestnut.

XVIII. Deciduous trees.—Birches, Hickories, Walnuts, &c.

XIX. Deciduous trees—Catalpa, Cherry, Locust, &c.

XX. Deciduous trees—Maples, Basswood, Magnolia.

XXI. Wood industries. Wood products.

XXII. Relation of forests to climate. Relation of forests to temperature, precipitation. Relation of forests to water supply.

XXIII. Relation of forests to water flow. Relation of forests to floods and erosion. Relation of forests to wind. Relation of forests to health.

XXIV. Economic relation of forests to the State and Nation. Use of public lands. Forest reservations.

XXV. Forestry education. Forestry as an occupation.

It is not claimed for this brief course that it gives a complete exposition of the subject, or that we are able to illustrate it and give it so full treatment as we could desire, but that it does for forestry just what we do for entomology, rhetoric, German or any single subject in our College curriculum. Those who intend to follow forestry as a business or profession would need to spend much time in further more critical, as well as more practical study.

Instruction in horticulture, as outlined in the catalogue, is carried on chiefly by my associate, Assistant Professor Butz. All the ordinary operations of horticulture are studied and illustrated in a thoroughly practical way, and in addition particular attention is given to certain lines, such as seed-testing, forcing, etc. This work being carried on with or succeeding the study of botany becomes much more than that of the mere manual of operations. The careful student cannot fail to get a much more thorough knowledge of the principles underlying them, and thus be prepared for a more intelligent and more satisfactory practice as a horticulturist.

The operations of making and applying spraying mixtures of various kinds have been both practically and theoretically illustrated by all the horticultural students of recent years.

The growth and enlarged scope of the Correspondence Courses have entailed increased work upon all who are connected with them. The papers when returned come in at irregular intervals, and are very different as regards length and completeness. To read them is not so much of a task, but they frequently need correction and sometimes reply, in order that the students may not get wrong ideas. Sometimes queries arise in the student's mind and he writes for fuller information. All of this cuts seriously into one's time, but it is doubtless a legitimate part of our work, and it is not referred to here to make complaint. An analysis of the patronage of this course is interesting in showing what class of people is interested in it and benefitted by it. I have not attempted to do this except as relates to my own subjects, and that only in a general way. A considerable proportion of the students are outside of the State of Pennsylvania, some from the extreme Eastern and the Pacific Coast States. The larger number, too, are not young pupils, for whom the work was primarily, at least, intended, but are mature men in all ranks of life and kinds of business; the majority, however, are either directly engaged in some form of agriculture or quite interested in it. By far the best work has been done by the last named. Teachers, preachers and others seem to have been prompted by curiosity more than anything else, and in some cases have dropped out without completing the course.

If I am correct in these matters, it seems a necessary inference that this is nothing more nor less than university extension work, no matter by what name we may call it. If so, this is another case in which The Pennsylvania State College is getting scant credit for a very important educational service unlimited by age, sex or place of residence of the beneficiaries.

Acting under the general agreement with the State Department of Agriculture, I have, to a limited extent, taken part in the Farmers' Institute work, but the calls seem to be increasing and the time lengthening.

Very respectfully yours,
W. A. BUCKHOUT,
Professor of Botany and Horticulture.

State College, Pennsylvania, May 24, 1900.

# IV.—CHEMISTRY.

To the President:

Sir—My report of last year was devoted almost exclusively to a somewhat theoretical study of what the work of a Department of Chemistry in a wide-awake Technical Institution at the present time ought to be, after which in a few paragraphs I sought to show that the work of our own Department of Chemistry is being carried out along the lines indicated by the most advanced discussion of the day. Scarcely any space was given to the consideration of our equipment, our instruction force, or our limitations.

This year I would like to review as briefly as possible, the situation in which we find ourselves as regards actual working conditions confronting us in the contemplation of the task we have to perform in the next twelve months.

The Quantitative Laboratory. Our laboratory for Quantitative Analysis, large enough for the six or eight students who were likely to seek instruction in this subject at any one time when the building was first occupied, ten years ago this session, has long since been outgrown, and now, for the forty or fifty in actual numbers who come to us for instruction in this branch, is utterly inadequate. By making several divisions of students we have thus far been able to schedule all work assigned to us, but we have about reached the limit. There are nominally twenty-four working places, but the laboratory is sadly over-crowded when the full number is present at one time. Though the forty or fifty students who demand accommodations at at present, have, as just stated, been thus far provided for, yet the actual number of hours from Monday morning to Saturday noon is a fixed quantity and we have practically exhausted the possibilities. Allowing two or three to overflow into the private laboratory as we have done, affords but an imperfect and unsatisfactory relief purchased at the cost of much sacrifice of convenience and interference with work. Already the pressure of larger numbers is upon us. The very next winter will introduce a larger number than ever before if our curriculum of many years standing is maintained. The limit of physical possibility will be reached, and I am forced to inquire, what can be done with this number of students? I am basing this view on the numbers of students now in College classes, and not on any prospective numbers whatever. Should the next Freshman Class be again a small one, of such numbers as we were accustomed to in the past, I could see that we might so divide the numbers next winter as to bridge over this difficulty, but if the next incoming class is as large as the present Freshman Class, and I trust there is no reason to suppose the contrary, the pressure of numbers in our quantitative laboratory will at once become so great that either some of our work must be stopped or some of our students be turned away from the laboratory. This year some advanced Chemistry students were crowded out of their regular places and forced to work under disadvantages in order to permit some beginners in Quantitative Analysis, most Electric Engineers and a few others, to have a place to do their work. This is not right and ought not to be repeated, though as a purely temporary measure, I was willing to allow it to take place.

The Organic Laboratory. In planning a Chemical Laboratory for The Pennsylvania State College no provision was made for practical work in Organic Chemistry, an omission which is almost as incomprehensible in these days as would be the omission from a College curriculum of any provision for teaching Mathematics, or Political Science. While Organic Chemistry might be omitted from a course in Metallurgy or other engineering specialties which involve some Chemistry (though I believe such omission is always to the disadvantage of a liberally educated man), or perhaps from the curricula of those denominational or other Classical Colleges which aim no higher than to keep abreast of the fairly good High Schools of the land, it certainly cannot rationally be omitted from the courses of study in a College which aims to turn out educated and well trained chemists and to stand in line with other institutions of higher education.

There can be no adequate understanding of the processes of Physiological or of Agricultural Chemistry, nor yet of the great industries of gas and oil, pulp and paper making, sugar refining, food preparation, dyeing, bleaching, etc., etc., without a systematic and thorough study of Organic Chemistry. The specialist must study this side also, if for no other reason, because of the valuable light which it throws on the theory of Inorganic Chemistry.

Our students in this subject have thus far been crowded into a small room in the basement, never intended for such use, and most imperfectly adapted to it. Here again, so long as our special students of chemistry numbered no more than three or four in a class, we managed fairly well; when the number reached about six, as it has been for the last two years, we could still do our work, though any such thing as individual possession of apparatus, or assignment of working places has long since had to be abandoned, to the very great disadvantage of the work. But next year we have eleven students in sight for this branch of the work. I can not understand what they are to do. It will be impossible for them to accomplish their assigned work with our present conveniences; it cannot be thought that a dozen students can be crowded into a room not large enough to hold six. What is to be done?

Balance Room and Library. Here again is met a problem which was simple enough five or ten years ago, but very difficult of solution now. So long as one small room serves for both library and weighing room, all reading room work for all branches of our Department instruction, and all weighings pertaining to the quantitative work must be performed within the confines of one small room, now too small to serve adequately either purpose alone. Many times there is a congestion here which is very objectionable; students have to wait for balance conveniences and are much in each other's way aside from causing serious detriment to work by delay and loss of time.

Gas Laboratory. The important subject of Gas Analysis, valuable and necessary as it is not only for the Chemist, but for the mining and mechanical engineer as well, we have been compelled this year to omit entirely, except in so far as it is covered by lectures. But lectures or recitation work in such a subject as Gas Analysis is of next to no value, unless accompanied by actual practice in performing the analysis of gaseous mixtures. It happens that this is a subject which, though it requires no large consumption of time, does make larger demands on the instructor than most others. It involves a great deal of rather complicated apparatus, and this in turn requires much of the time of an instructor to keep it in order for work, so that I am always unwilling to attempt a class of a dozen students in this work unless I can have at least two teachers in charge all the time, and really think it almost unprofitable unless we can control three. For the past few years we have had a class of about a dozen in this subject and have placed sometimes three, and sometimes two instructors in charge, but never less than two.

It may not be known to some of the Board of Trustees, that we have had no proper place in which to perform this work. Indeed, there was, at first, no place at all, but some four years ago we constructed a long rough table in the unfinished attic of the Chemical building and, the subject occurring in the first part of the Spring term, I have taken the class there, in spite of the unevenness of the temperature which often renders Gas Analysis results worthless. More to be feared is the inclemency of the April days, there being no opportunity whatever for artificial heat. More than once a warning has come in the shape of a severe cold contracted in this unfinished room, on the part of student or intructor, and although students have many days peformed their work there in their overcoats, and we have had to adjourn on certain other days because of too great exposure, thus suffering a waste of assigned time, the work has nevertheless been kept up until the present year. Yet I have often regarded it as unwarranted to permit the maintenance of a branch of our work under such untoward circumstances.

So, when the spring term was approaching and I found our instruction force so cut down, and the remnant of it so overworked that it was imperative that something be cut off, I secured executive permission to omit Gas Analysis instruction for this year for the twofold reason. Should our force permit its being resumed next year, I should still be reluctant to return to the unfinished room in the attic, a place so bad that the subject might about as well be omitted, as undertaken under such conditions. I sincerely hope that provision may be made very soon for a suitable gas laboratory, or at least one which may serve that purpose for a portion of the year.

Qualitative Laboratory. Fortunately I need not complain of the inadequate size of the laboratory for beginners in elementary and qualitative work. This hall is large, having places for seventy-two students, which is as large a number as I think should ever be brought together in one room at one time for this purpose. It is true, however, that the size of the present Freshman class is such that two laboratory divisions are necessitated where one has hitherto been sufficient. This, of course, doubles the effort of instruction. As an illustration, I am now conducting sixteen hours per week of the most exhausting work which I ever perform, while eight hours have always sufficed before. I mention this circumstance in no spirit of dissatisfaction whatever, but merely to call attention to it as one of the outlets through which some of the surplus energy of the instruction force can escape. As a matter of course, this calls for duplicated work on the part of the laboratory assistant also. The same conditions will presumably hold every session from now on. Indeed, I fully anticipate that it will be necessary to make two divisions of the engineering section of the Sophomore Class in Qualitative Analysis next fall session. We shall surely avoid it if possible, but at present it appears inevitable.

Lecture Room. The largest auditorium which we possess seats one hundred and seven persons. It was filled to overflowing last session. Chairs had to be brought in to accommodate all who attended the course of lectures in General Experimental Chemistry for beginners. Possibly ten more permanent seats can be provided, but then all available space will be occupied. Even with chairs in the aisles not more than one hundred and twenty-five persons can be seated and we must therefore divide the class when that number is reached, presumably next winter, and thus duplicate another portion of the work making a further draft on the resources of the instruction force. It will be remembered in this connection that we have only one supplementary lecture hall. A third recitation room, though not an immediate necessity, would prove a most valuable addition to our conveniences and one which has often been temporarily needed. On repeated occasions the schedule committee have been forced to arrange for three of our recitations or lectures to take place at one hour, and yet we have thus for been able to adjust all such cases by holding the exercise with the class of smallest numbers in the library or some other inconvenient place.

Library Equipment. We have been able to make no additions to the chemical library, aside from subscriptions to a few journals, for a number of years. It is needless for me to say that we are sadly behind the times in this respect. To keep our advanced work up to the standard of excellence we have maintained in the past demands frequent and searching reference to the most rapidly growing literature of our science, a pursuit in which we are always handicapped, if not completely blocked at the first turn. Five years ago I reported my belief that our department library was one of our weakest places, and expressed a hope for the privilege of spending five or six hundred dollars in new books and new subscriptions within a year, a hope which I regret was not in that year, nor in any subsequent year realized.

Museum. It is a matter of disappointment to me that work in advancing the museum of chemical industry has had to cease by reason of lack of time and of funds. The museum is, however, one of the strongest points in our equipment. It made rapid strides during the years in which we could give it a little time and effort, and became a most important factor in instruction in applied chemistry. The cessation of our labor along the line of its development, due to temporary lack of funds and time, is, I trust, destined to prove only an intermission, and that of short duration.

General Equipment. Nothing has been added to the equipment of the laboratory for some years. In fact rather the reverse is true, for while nothing has been carelessly allowed to deteriorate, still the suplus stock of staple goods which it was our practice to carry on hand a few years ago, knowing that it was better economy to anticipate our wants and purchase in large quantities in advance of our needs, making use of the low price of duty free importations from Europe, has mostly disappeared. So pressing was the need of funds for certain lines of our work that we have gradually allowed our stock of regular goods to be diminished; for example, no importation of chemicals has been made during the current collegiate year, for the first time since my connection with the College. Even such matters as certain repairs to building, heating apparatus, ventilation fan, etc., have in more than one case demanded immediate care, the expense of which could not be met outside of the department, consequently had to be so provided for that the ultimate effect has been a diminution in stock of chemicals and apparatus. This is not as it should be, but will, I trust, be remedied in a year or two.

Recapitulation. Reviewing briefly the important needs which I have outlined above, I would now assemble as urgent, immediately urgent, the three items:

1. Greater quantitative laboratory space.
2. More room for practical organic work.
3. Some provision for gas analysis.

Further, I would again make the statement that these three branches of our work can not go on for more than a short time without some provision for laboratory space. This is a physical obstruction which we meet here, of such nature that I am powerless to avoid it and I have no option but to present the facts as they are. In doing so I can assure you that I have not made use of a word or an expression which in any measure exaggerates or otherwise than most faithfully represents the situation as I see it.

Other needs outlined above, not included in these three particular ones, important as they are for the welfare of the Department, may of course be postponed without curtailing or seriously impairing our work, but not so the three to which I have just called special attention.

Department Force. I cannot close a report of this character without mentioning something of the needs of our force of Department workers. Shorthanded, as repeatedly mentioned in my annual reports of the last few years, we found ourselves doubly so at the opening of this year when the laboratory assistant, Mr. F. T. Beers, who had served the College faithfully during his connection with the force, withdrew to accept a commercial position and I was not permitted, because of lack of funds, at once to fill his place. Without this assistance upon which we have come to place great dependence, the work of the last fall session, especially in Qualitative Analysis with Sophomores of all courses, was very unsatisfactorily performed. I may truthfully say it was seriously impaired.

This difficulty was greatly increased by the necessary withdrawal from the total strength of the Department of Dr. F. J. Pond's time to an extent sufficient to enable him to carry the work formerly done by the Assistant Professor of Mining Engineering and Metallurgy, and of enough of Dr. W. J. Keith's time and attention to care for the subjects of Crystallography and Mineralogy. These are serious drafts on our force to which I gave most reluctant consent. That they have sadly crippled us can not be denied. Upon my appeal in the fall term, the Executive Committee kindly allowed my request for the restoration of the laboratory assistant for the winter and spring sessions of the current year, a most needed, though only partial measure of relief.

For this position the services of Mr. Charles M. H. Atherton, of our class of 1892, were secured for six months from January first, 1900.

But our work increases with incoming numbers, and, as has been stated earlier in this report, some parts of our instruction which have never required duplication before, must needs be duplicated next fall. Indeed, I do not see how the instruction work of next year can be accomplished without, first, the continuance of the assistanceship just mentioned, and second, the addition of one other teacher to the force. Such additional teacher ought to be a man of some experience, who can rank as instructor at suitable salary, and be entrusted with the conduct of classes, or better still, with the entire responsibility of some sub-department of the work, as for instance Industrial Chemistry and Gas Analysis. If obliged to get along with a beginner merely, as an additional laboratory assistant, the aid, though very appreciable, will not be so great as is needed since it is actual relief from the conduct of parts of the work which is most seriously required.

As our department work increases, another need will develop, not altogether remote now, which we shall find very important, namely, a person whose duty shall be to relieve us of all the care of the bookkeeping, accounting, issuance of apparatus, etc., as well as to act as stenographer and clerk. All this labor is now divided among the force, most of the clerical work devolving upon me, and the burden of correspondence alone, performed as it is without assistance, for a large and growing department, is no trifle. A systematic issue of apparatus by a person who should remain at all times in sole charge, would result in much economy.

In submitting this report, I wish to renew all former expressions of appreciation of the cordial support always extended to my Department by the President, the Executive Committee, and the Board of Trustees.

Very respectfully,
G. G. POND,
Professor of Chemistry.

State College, Pa., May 18, 1900.

# V.—CIVIL ENGINEERING.

To the President:

Sir:—The work of this department has been carried on during the past year in much the same way as heretofore and I will speak of only a few points in detail.

During the year 1898-9, on account of the illness of one of the instructors, we were compelled to carry on the work with a reduced force. This year, on account of the failure of the last Legislature to provide anything for the maintenance of the department, our force has been still further reduced, so that it has been necessary for us to do with two men the work which, for miximum efficiency, could well occupy the time of four. While nearly all the subjects scheduled have been taught, it has been found necessary to adopt methods which are far from satisfactory, such as assigning two classes to an instructor at the same time, and teaching classes in large sections instead of small ones. With the increase in the number of students that will come to us for instruction next year it will not be possible for us to do the work without another assistant.

During the past year we have been able to add to the equipment of this department apparatus for experimenting on the flow of water in connection with our work in hydraulics. This was purchased with funds obtained from the last appropriation.

The apparatus consists of a ten-inch riveted steel standpipe eighty-two feet in height, extending from the basement of the engineering building to the roof. In the basement and on the first floor provision is made for the attachment of plates provided with standard orifices, short tubes and mouthpieces, with valves for shutting off the water. The standpipe is supplied with water from a three-inch pipe which rises by the side of it to a height of about forty-five feet. A waste pipe of the same siz, also extends to the same height. By means of properly located valves the water in the standpipe may be kept at a constant level while an experiment is carried on. The height of water is observed in a glass tube provided with a graduated scale, which extends from the basement up to a height of fifty feet. Above this point the height is determined by a mercury column placed on the third floor.

On the second floor a system of three-inch pipes affords an opportunity for studying the flow of water in pipes. In this system is a Venturi Meter, which furnishes a very accurate means of determining the amount of water flowing through the system. These pipes discharge through a standard Underwriters play pipe which is provided with a set of nozzles of different sizes.

The nozzles and the standpipe discharge on the second floor into a steel weir tank ten feet long and five feet wide, having an adjustable crest. The overflow from the weir tank goes to either one of two large cylindrical measuring tanks in the basement. Those tanks have a capacity of two hundred cubic feet (about fifteen hundred gallons) each, and have been carefully calibrated so that the amount contained in them at any time is indicated by a glass gage. As each of these tanks discharges through a six-inch quick action valve, they can be emptied in a very short time, thus permitting accurate and rapid measurement of large volumes of water. Smaller tanks which can be placed on platform scales afford a very accurate means of determining smaller volumes of water.

The entire apparatus is so arranged that a great variety of experiments can be performed. One experiment affords four measurements of the same water by different methods, viz: By the Venturi meter, by the hose nozzle with a pressure gage at the entrance, by the weir, and by the measuring tank. The latter gives an accurate measurement by which the laws of flow may be investigated and the common formulae for the various conditions may be checked.

The promptness with which positions were secured by the graduates in this department last year was very gratifying. Of the eight graduates, seven went into railroad work, one or more going to each of the following railroads: New York Central and Hudson River; Pittsburgh, Fort Wayne and Chicago Railway, and the Illinois Central Railroad. One man found employment with the Carnegie Steel Company. The indications are that this year's class will find satisfactory employment without difficulty, one man having already been offered three positions.

Trusting that you will not permit this department, which is among the oldest in the College, to suffer seriously on account of the withdrawal of the State appropriation, and that the present condition of affairs may not occur again, I remain,

Very respectfully yours,
F. E. FOSS,
Professor of Civil Engineering.

State College, Pa., May 24, 1900.

# VI.—ELECTRICAL ENGINEERING.

To the President:

Sir:—I have the honor of submitting a report for the Department of Electrical Engineering during the College year 1899-1900. In general it is fair to say that the improvement in our system and the growth of efficiency in the work has been as pronounced as in preceding years. This continuous development is the result of the sound policy you have inaugurated and pursued, in connection with the Board of Trustees, with reference to the entire collegiate work of the course.

## Character of Studies.

In the previous reports of this Department you will find more or less detailed descriptions of the various studies offered in electricity. As very few changes in the general method of treatment have occurred since that time, it is not now needful to repeat these descriptions. The character of the work with reference to the relative amount of attention given to theory and to practice is, however, of great importance and is one which has not been touched upon in the preceding reports of this Department. As a first statement with reference to this subject, it is safe to say that the Course in Electrical Engineering as arranged at this Institution may fairly be considered to be eight-tenths theory and two-tenths practice. The back-bone of the Course, which begins with the Spring term of the Sophomore year and runs through to graduation under the various titles, Electricity and Magnetism, Dynamo Electrical Machinery and Alternating currents, is essentially a stiff, continuous, theoretical study of the various physical phenomena observed in dealing with electricity and magnetism. This theoretical work is further developed by thorough courses in the transmission of Electrical Energy, Electro-metallurgy, and Instruments of Precision. A comparatively small amount of time is assigned to mere practical details in the application of electrical power to lighting, traction, speech-transmission, heating, manufacturing, etc. In the drafting rooms and laboratories exactly the same relative condition exists. Here the experiments or problems to be developed by the student are such as will enable him to grasp the physical laws with which he must deal little time being assigned to technical details.

There are two extreme types of courses in Electrical Engineering offered by colleges. In the first nothing is taught but the theory of electricity and magnetism, essentially no reference being made to the utilization of the laws and principles which are studied; while the other class offers almost no theory, but is confined closely to teaching the details of installation and construction as found in the engineering field. It is conceded by all professors of electrical engineering who have developed worthy courses of instruction. that neither of these classes is efficient or satisfactory. The first method may be likened to the teaching of history without pointing to the influences, results, and lessons which are to be drawn from the events considered; and the second is somewhat similar to teaching Geometry by having it committed to memory instead of following the reasoning processes. A mean between the two classes is that followed by the eight or ten best courses in the United States. Such a mean, leaning toward the theoretical side, is followed by the Course at this Institution. The various principles or laws are carefully developed and studied, starting with the most fundamental phenomena and after this has been done their effects upon applications and utilities are briefly noted. By such a system the student not only obtains an idea of the utility of the subject studied, but also is enabled to conceive very clearly its true physical meaning. It is impossible for such a conception to be obtained by a mere theroetical development, lacking practical illustrations or applications. The fact that whereever our men have come in contact with the graduates of other Colleges they have had reason to feel that they were entirely able to hold their own is substantial evidence that this method is a proper one. The false impression is quite prevalent that the drafting room and laboratory are strictly for practical training. The truth is that both of these divisions in a good electrical engineering course are just as largely theoretical as are the lecture and recitation.

The result of a course properly arranged with reference to theory and practice should be to enable a man to master his profession and meet new problems as they arise with intelligence and success. Where the course is too theoretical the young engineer shows an impracticability which is apt to bar his progress materially. while the man who has had the opposite training lacks the essential mental development and understanding which is secured by a thorough collegiate education. He is, therefore, apt to remain in a position which is similar to that of a mechanic.

## Department Growth.

Since the inception of the Department of Electrical Engineering in the Spring of 1893, there has been not only a moderately steady growth in equipment and efficiency of methods, but also in the number of students enrolled in the catalogue as taking the Electrical Engineering Course and in the number of men graduated each year. The number of students taking the Course beginning with the catalogue year 1892-1893 stands,

| | | | |
|---|---|---|---|
| 1892-3,............... | 40 | 1896-7,............... | 65 |
| 1893-4,............... | 57 | 1897-8,............... | 65 |
| 1894-5,............... | 63 | 1898-9,............... | 68 |
| 1895-6,............... | 64 | 1899-1900,............ | 92 |

The number of men who have been graduated in the Course beginning with the Spring of 1893 are for the same College years,

| | | | |
|---|---|---|---|
| 1892-3,............... | 0 | 1896-7,............... | 9 |
| 1893-4,............... | 3 | 1897-8,............... | 8 |
| 1894-5,............... | 8 | 1898-9,............... | 11 |
| 1895-6,............... | 9 | 1899-1900,............ | 17 |

It will be noticed that in both of these tabulations the growth is more or less by steps, which is likewise true in other institutions. It is seen, however, that though the rate of growth has been more or less irregular, the number of students has increased about one hundred and ten per cent., while the number of graduates has increased from zero to seventeen. Two things are clearly indicated by the tabulations: First, That the demand for training in Electrical Engineering at this Institution is steadily increasing; and second, that the number of men having the ability and desire to complete the course is increasing at a still greater rate.

The call for this Course is naturally explained by the extensive industrial applications of electricity in Pennsylvania to mining, manufacturing processes, traction, lighting, etc. From all indications the conclusion may fairly be drawn that the situation of the Institution is such as to make a strong demand upon it for suitable facilities in the training of men for the Electrical Engineering profession.

## Instructors.

The Department is now completing the second College year with only two Instructors. This does not include a small amount of aid given by student assistants in the Spring session. It has not been possible to carry on the work with this number of men in the thorough manner that I believe the Board of Trustees would desire. The number of students in Electrical Engineering per instructor is much greater here than in other institutions of similar standing with which I have made comparison. I, therefore, earnestly request that a laboratory assistant who is capable of constructing apparatus be added to the force of the Department at the earliest possible time. In making this suggestion I would add that it might be well to have a man who can not only assist in the laboratory but who can also do a large part of the necessary repairs to the Electric Light and Power Plant. Such an arrangement would be of great advantage as Mr. Albert Emerick's time is now so fully occupied that it has been necessary to employ a considerable amount of day labor to assist him in making repairs to the plant. If such an arrangement could be made, part of the expense of the assistant would fairly be chargeable to the electrical lighting account.

Mr. F. F. Thompson, our Instructor in Electrical Engineering, has been doing very satisfactory work and I think deserves a substantial recognition. I have already informed you in my previous report of his extended and valuable training for the position he now holds. I have nothing to say other than high praise in referring to his work. If you could arrange to give him an increase of salary or some other recognition, it would certainly be well merited.

## Equipment.

During the past year it has been possible to add very little to the previous equipment of the Department, on account of the very limited means appropriated for general expenses. In fact the small amount so given is entirely inadequate to maintain our present equipment properly, to say nothing of supplying the new apparatus absolutely essential to the work. I beg that you will give your earnest attention to this imperative need of the Department for a larger maintenance fund. The fact that we never have had the means for duplicating apparatus, while the number of students calling for instruction in electrical engineering has been increasing rapidly, renders it absolutely essential that some regular expenditure be made to enable us to continue our regular schedule. As the work progresses, it is found necessary to use all kinds of devices and temporary expedients to piece out the small additions that we are able to make. You can readily see that with such limitations upon the Department it is difficult to maintain the high standard you desire.

The foregoing statements in regard to equipment have reference merely to keeping our work up to its past grade as the classes increase, and not with the view of improvement. I assume that during the coming year there will be but a small fund for enlargement of the equipment, but nevertheless the matter is one of so great importance that it should be brought to your mind for action whenever the financial condition of the College permits. The fact is unquestionable that unless a large appropriation is made at once, the Department will lose standing as compared with those of similar institutions. Nearly all the universities or colleges giving strong courses in Electrical Engineering have been obtaining generous sums yearly for new equipment from the time of their establishment to the present. Not only is the average amount per year received by the institutions with which I am familiar greater than at our College, but the number of years the courses have been established is also greater. As you will remember, the Department at this Institution was not put into operation until the latter part of the College year 1893-4, while in other institutions similar courses were established as early as 1875.

In the beginning, there was no equipment available for the Department at the College. During the first year three machines were donated outright to us by the United Light and Power Company, of New York city through the instrumentality of Frederic Darlington, '86, and one machine was furnished by the Edison General Electric Company at the nominal price of $50.00. A necessary number of high grade instruments and supplies for the Department were purchased. This small equipment, a large portion of which was donated to the College, was the nucleus upon which the present laboratories have grown. During the succeeding years, a considerable amount of machinery has been donated and three machines have been purchased at a fair consideration from the Department of Physics. Essentially all the measuring instruments, voltmeters, ammeters, galvanemeters, electrometers, etc., have been obtained at a large expense, as this class of apparatus cannot be gotten of good quality and at the same time inexpensively. These statements indicate that, though the available funds have not been great, yet the equipment has been steadily improved each year. On the other hand, it must be remembered, as suggested above, that such institutions as the Massachusetts Institute of Technology, Cornell, Leland Stanford, and the Universities of Wisconsin, California, Ohio, Michigan and Illinois have not only had a larger yearly fund at their disposal, but have had in every case a longer period for development. As these institutions have all been well managed in their departments of Electrical Engineering, it is evident that they have had an opportunity to gather together much more extensive facilities than has been possible here. The institutions above may be considered fairly comparable in the work done in Electrical Engineering to that of this Institution. It might be said in passing that there are a great many Colleges having courses scheduled in Electrical Engineering which scarcely deserve that name, as the work is done with almost no facilities either in the way of an engineering faculty or equipment. Such institutions turn out a large number of graduates entirely unfit to grapple efficiently with professional work. These institutions do not, therefore, form a basis for comparison.

It is evident from the statements already made that if the Department of Electrical Engineering is to hold its own with those of the better Colleges, it must have a large fund put at its disposal at once. It should have the sum of at least $10,000 to expend immediately and should then have generous amounts yearly to put into new equipment. There is one other reason which makes a large annual appropriation necessary. That is, the rapidly changing character of the applications of electricity in the engineering field. When the Department was started, direct current machinery of from 100 to 500 volts was used almost exclusively, and largely for lighting and street railways. Since then polyphase currents have been developed and are rapidly superseding the direct and single phase alternating currents. Transmissions of power with voltage as high as 30,000 and distances as great as 40 miles are being installed with the near prospect of still more radical changes in the future. Electricity is being rapidly applied to the mining industries of the country with the consequent development of new types of machinery to meet the conditions. Suitable apparatus is being designed and extensively applied to the driving of our great manufacturing establishments. The original street railway systems are expanding into great inter-urban roads with consequent changes in types of apparatus. Electricity is becoming a most useful agent in the field of Industrial Chemistry. One company alone utilizes 20,000 horse power for this purpose. The enclosed arc lamp is taking the place of the open lamp. The familiar incandescent lamp with its carbon filament glowing in a vacuum bids fair to be soon displaced by a radically different form of electric light. The telephone systems of the country are in many respects unlike those of six years ago. And finally it may be said that the design, installation and methods of application of electricity have been essentially revolutionized within the brief period of the life of this Department.

## Floor Space.

I have already called your attention to the cramped quarters in which the electrical work is now being carried on. The electrical equipment was first established in the mechanical laboratory but inadequate floor space soon caused it to be placed in what are frequently designated the fan and dark rooms. It was not long before this new disposition was found insufficient, and the present quarters under the carpentry shop were assigned to the Department. We are again in such straits for suitable floor-space that it is entirely impossible to carry on many lines of our work in a suitable manner. The Department needs badly at least double the room that is now assigned to it, and this space should be designed and arranged with special reference to the lines of work to be pursued. Entirely satisfactory arrangements are impossible in a building originally planned for other purposes. My hope is that a wing can be added to the Engineering Building that will give the needed facilities.

## Theses.

In a number of the previous reports will be found more or less detailed descriptions of our laboratory work which will serve as a fair basis by which to judge the character and scope of the training during the past year. There is a good deal of this work, however, which deserves further mention. The theses spoken of below are of this character.

Messrs. J. H. Siegfried and A. H. Berger have spent a large amount of time in completing the construction of a 60,000 volt transformer, which was originally designed by Messrs. H. P. Wood and J. L. Stewart. The excellent character of the work is shown by the fact that the transformer will not only maintain its very high secondary voltage but also in every way seems to have met the conditions of the original design. To indicate the difficulty of the problem with which they had to deal, it may be said that there are very few systems using over 20,000 volts and none have ever been installed to use the voltage in question. These men and their successors will carry on investigations with this piece of apparatus with reference to the limit of voltage that can be practically utilized for long distance transmissions. The importance of this work will be appreciated when it is understood that the cost of copper for transmitting electrical energy varies inversely as the square of the pressure.

Messrs. G. C. Shaad and D. S. Morgan are experimenting along the lines originally developed by Messrs. V. M. Weaver and W. B. Dawson, of last year's class. The object sought is an economical method of splitting up single-phase alternating currents into polyphase currents. Special apparatus has been carefully designed and constructed for obtaining this end and from the data so far obtained the final results give indication of being of value to the electrical industries. This investigation cannot be completed by this class and must, therefore, be continued by the one succeeding. To the present time, when it has been found necessary to "split" an alternating current for the purpose of starting induction motors, only unsatisfactory methods have been available.

Messrs. G. E. Guy and R. J. D. Hoover have designed and constructed an automatic synchronizing switch for throwing alternating current generators into parallel. Such machines have always been coupled together by hand at the expense of much time, and where the attendants are inexperienced, with the accompaniment of more or less serious accidents. The apparatus constructed by these men appears from the tests made upon it by the use of our laboratory generators to be an improvement over the hand method.

The remainder of the theses are entitled: Complete Incandescent Lamp Tests by A. M. Pierce and J. N. Nesbit; Remodeling of an Electric Light and Power Plant by W. A. Krebs and J. Agnew; The Design of an Electric Railroad between Tyrone and Bellwood by D. S. Miller and E. J. Thompson; Experimental Investigation or The Characteristics of a Two-Phase Induction Motor by J. McKinley and C. C. Mattern; Design, Construction and Test of a Single-, Two- and Three-Phase Rotary Converter by D. H. Plank and H. C. Glenwright; and Methods for Increasing the Earning Capacity of the Electric Light Plant at Watertown, Pa., by C. Bolard. These theses as may be seen from the titles all consist of original investigation and research work.

## The Electric Light Plant.

To make the system of distribution from the Electric Power Plant complete, it is desirable that feeders be run to the group of buildings surrounding Dr. H. P. Armsby's residence and to the Agricultural Experimental Station buildings. The first should run through the tunnel to the Chemistry and Physics building and from there on should be placed underground in interior conduits. A needed improvement is also the placing of the wires running from the Botanical building to the Grove in interior conduits. The same disposition would also be desirable in case of the wires running to the University Inn and to the Beta Thete Pi fraternity, though these are not quite so unsightly.

There is still more or less re-wiring that should be done to bring the plant up to the proper stage of insulation. This is a matter that cannot be delayed long as the old methods in use for wiring were such that a break down of the insulation is liable to occur at any time. The pole lines that cannot be removed by placing the wires underground should all be renewed as they have been standing more than their normal life.

In concluding my Report, I wish to renew my sincere thanks to you and to the Board of Trustees for the kindly and valuable assistance you have rendered me in my College work and to assure you that I shall endeavor to merit your aid by careful attention to the interests of the Department entrusted to my care.

Respectfully submitted,
JOHN PRICE JACKSON,
Professor of Electrical Engineering.

State College, Pa., May 21, 1900.

# VII.—ENGLISH AND RHETORIC.

To the President:

Sir:—How to turn out from our colleges young men and women who can write their mother language with ease and accuracy is, as you well appreciate, one of the serious problems of modern education. Could the college control the child's environment and early training; could it dictate the methods of preparation for the period of advanced work, there would be a notable lessening of the difficulty; but manifestly this is impossible. The average student comes from a home where the vocabulary is small and the diction and syntax may be slovenly, where little or no effort is made to secure correct and easy English, and where good literature is not always abundant. He attends schools where English work is often sadly neglected, and he fits for college where this important subject receives but scanty attention. As a result he reaches the college deficient even in the common mechanical processes—spelling, grammatical construction, punctuation, and division into paragraphs. He has moreover a limited vocabulary, an awkward hand, and a timid and halting pen. The writing of his English exercises is regarded by him as one of his hardest tasks. Such a student is by no means the exception in our colleges. Of the eight hundred or more who have sat in my class room during the past six years not more than one-fourth were prepared to do work in English of a distinctly college grade, and over half were deficient in the fundamentals that should have been learned in the lower schools.

To make from such material, in the short time that can be given to English work, men who are worthy to bear the diploma of a college is wellnigh impossible. Too often the college can do nothing but furnish those foundations which should have been laid in childhood. The fault lies largely with the lower schools and, until they are made to understand fully their deficiencies in this respect and their responsibility, the colleges will continue to reap the fruits of their sowing.

The English department, as the very first step in its work with Freshman beginners, endeavors to make each student appreciate the imperative necessity of ease and accuracy in the use of the mother tongue. It is impressed upon him that by his English he is classified in society; that whatever calling he may enter, whether engineering, chemistry, agriculture, law, divinity, his mother tongue is to be his chiefest tool; that no man can reach a commanding success in any

LIBRARY OF THE UNIVERSITY

calling in life and neglect the art of English composition, and that slovenly English almost invariably is the index of slovenly thinking. A lively realization of the importance of a subject is the first stepping stone towards a mastery of that subject.

From the very first the student is required to write. No art can be acquired without constant and painstaking practice and the manipulation of language is the most subtle of all arts. The student is made to write always upon things with which he is perfectly familiar; things that are specific and within the realm of his enthusiasms. The favorite subjects of the old rhetorics: "War," "Disease," "Youth," "Morning," "Autumn," "Honesty," and the like, which have paralyzed completely so many youthful pens, are avoided like contagion. The student is called upon to criticize or defend in two hundred words the "guards back formation;" he describes an historic spot that he once visited; he tells how he passed the entrance examinations; he defends his choice of course; he details the circumstances that led him to the college; he describes in a few words a building on the campus so that the instructor can guess at once which one he has in mind; he describes familiar things with the eye upon the object; he uses his imagination and tells what his maiden aunt would say if she could see his room at times or witness a foot-ball game; he looks at the college life from the standpoint of the farmer in the neighborhood; he tells of curious people whom he has seen; laughable experiences, and exciting incidents. By and by it dawns upon him that composition is not so hard after all.

Hand in hand with the composition is the daily recitation upon the fundamentals which underlie the art. These are illustrated by extracts from the essays; and by daily paragraphs written in the class. Every essay passes under the blue pencil of the instructor and faults are indicated in the margin. Often the composition is re-written by its author sometimes many times over. Weaker students are given frequent conferences; their faults are discussed and their habitual errors are kept constantly before them. Manifestly such work requires much of the instructor. To hold oneself steadily hour after hour to the task of reading inferior and often grotesque English is nerve wearing in the extreme. But there is no other way. The instructor in English who would shirk this dismal duty has certainly mistaken his calling.

The exercises are varied constantly. Often the instructors in other departments are called upon for subjects in connection with work which the students are doing there. Often reports are required upon some branch of industry with which the student is perfectly familiar; the making of coke, the drilling of oil wells, the rotation of crops, etc. Descriptions illustrated by diagrams are sometimes required. Good results after the first session are secured by allowing the students to exchange themes and correct and criticize at will. All such corrections, however, must later pass under the eye of the instructor. The instructor sometimes writes upon the essay all the questions which it raises in his mind. But it is needless to dwell further upon methods. Suffice it to say that the practical standpoint is never lost sight of, and that by the end of the year the student has at least gained a clear idea of what good English is and what his own failings and excellencies are.

With the exception of a small amount of forensic work in the Sophomore and Junior years the student in the technical courses gets no regular training after the first year. The students in the general courses, however, have a chance to pursue the subject still further. The late revision of the General Science Course has made it possible to offer as much work in the history of the English language and literature as is given in most classical colleges. The course has been arranged in logical sequence. Beginning with a study of bibliography, which aims to make the student perfectly at home in any library, it introduces him first to his own American literature, then to the history of the English language, and then to a survey of the whole field of English literature by periods. During the closing session the student is required to make a critical study of some period or phase of literary history working wholly from original sources.

The department is continually handicapped in its advanced work in English literature by the condition of the College library. An original expenditure of at least $500 with an annual allowance of not less than $100 will be necessary before the library can be used for original investigations of any real value.

The year has been in many respects a very successful one. The Freshman class came better prepared and has done better work than has any other since my connection with the Department. The recent revision of the schedule has distributed the English subjects so that more satisfactory work can be done than ever before, and the addition of elective subjects in literature to the General Science Course has greatly broadened the scope and general effectiveness of the Department.

Respectfully submitted,
FRED LEWIS PATTEE,
Professor of English and Rhetoric.

State College, Pennsylvania, May 19, 1900.

# VIII.—HISTORY AND POLITICAL SCIENCE.

To the President:

During the year 1899-1900 the work in the Department of Political Science and History has consisted of the following courses: (1) General History, five hours for the Fall term, and four hours for the Winter term; (2) Political Economy, four hours for the Fall term; (3) Constitutional Law, four hours for the Winter term; (4) International Law, five hours for the Spring term; (5) The Territorial Growth of the United States, four hours for the Fall term, and three hours for the Winter and Spring terms. The first course was required for all Sophomores; the second, third and fourth courses were required for all the seniors; the fifth course was elected by the seniors in the Latin Scientific course throughout the year and by the seniors in the course in Philosophy during the Winter and Spring terms.

In a community which is dominantly industrial in character, and in a college which very rightly reflects in large measure the industrial character of the community which it serves, there may be a tendency, not to deny, but sometimes to forget the value of work done in this department. It is not contended that the study of the political and social sciences will tend in any direct way to make a man a better engineer, or to give him a better technical education of any sort. The work in this department is not designed for such a purpose. The purpose of these studies is rather to broaden the mind of the student, increase his general mental power and grasp, teach him how to think in new ways and with reference to matters as widely separated as possible from the technical subjects which go to make up the main part of his course. But these studies are helpful to the technical student not merely for the purpose of general culture. They have a greater significance. These subjects bear directly upon the political problems which confront the people of the United States—problems which the industrial revolution of the present century have made prominent, and which the almost incredible industrial development of the last half of the present century is making daily more complex and difficult of solution. If republican government in the United States is to solve these problems it will be due to the wisdom of the people who established that government and of those who now and in the future support and maintain it. For this what is needed is a good citizenship; it is believed that the serious study of the courses in this department helps to produce such a citizenship.

With these facts in view instruction has been given during the past year. In the course in general history it has been endeavored to give the students, not so much a great number of unrelated facts, as a more or less comprehensive view of the whole field in a proper perspective. An especial effort has been made to impress upon the class the fact of the unity of all history, and to illustrate this unity by enforcing upon the minds of the students the way in which each so-called period of history is an outgrowth of the preceding periods, and has its roots deep in the past. In a word the aim has been to make the student see how the world in its political organization at the present time, has come to be what it is by natural process of development. The text used was Fisher's Outline of General History.

In the study of Political Economy a double aim has been kept in view. By following Walker's text, an attempt has been made to give the class a good grasp of the theory of society as organized for the production, exchange, distribution and consumption of wealth. The text, by its logical construction, and clear and forcible presentation of the subject, has served as an admirable guide in this, and few departures from its teachings were found necessary. The work of the instructor was limited for the most part to elucidation and illustration. Beside presenting the theoretical side of the subject several questions of a more practical nature were studied in the light of the principles which the study of the science as a whole had developed. In selecting these questions the instructor was guided by the desire to present to the class those subjects which would be of greatest practical benefit to the students in after life, e. g., Taxation, Money, Bimetallism, Banking, The Single Tax System, etc. These questions were presented partially in lectures, partially by text.

In the Course on Constitutional Law the attempt has been made, first to make clear the conditions which precedeed the government of the United States under the present Constitution, and the forces which brought about the change, and second to give to the students a firm grasp of the fundamental principles of our constitutional law as it exists to-day. The latter purpose occupied most of the term devoted to the subject of Constitutional Law as a whole. Reference to and comparison with the principles of English constitutional law were made constantly. Special emphasis was laid upon those liberties guaranteed to the individual against the Federal government, and those guaranteed against the State governments. In view of the late war and the problems with reference to the government of dependent territory which it has thrust upon the United States, it was thought advisable to present to the class in several lectures, a brief resumé of territorial administration in the past, and of the principal Supreme Court decisions which deal with the question of the status of territories in the political system of the United States. It is believed that the members of the class are able to discuss intelligently public questions with reference to their constitutional aspects.

In International Law the object has been to present to the class as clearly and succinctly as possible the rules governing the civilized nations in their intercourse with each other in peace and war. For this purpose Woolsey's book has been used with frequent reference to the somewhat clearer and more logically arranged work of Mr. Geo. B. Davis. Throughout the term constant emphasis has been laid upon the peculiarly voluntary nature of International Law, upon its flint characteristics; and the attention has been again and again called to the illustrations of the subject which are furnished by the present day intercourse of nations.

All of the above work has been required. The method throughout has been the text book method. By text book method it is not meant that any text has been slavishly followed, or any author's opinions accepted without question. It is meant merely that a text has in each course been assigned to the class, and, with few exceptions, daily recitations have been required. The recitations have been in the nature of a familiar conversation. It has been the aim of the instructor to present the subject treated of in the lesson by a series of questions. The questions have had for their primary object, not the ascertainment of what the students have memorized, but the careful building up of the subject in its logical and essential features before the eyes of the class. Where the answers elicited or the text itself have been deficient or confused, the instructor has attempted to supply what seemed necessary. This method it is believed has proved successful and is the only one possible in these courses. The students in all of these courses have shown a good degree of interest, of industry and of faithfulness. The personal attitude of the students towards the instructor has been without exception, courteous and gentlemanly; it has never been necessary in any of the above classes to give a moment's thought to the question of discipline.

Only one course in this department was elective during the past year. The subject treated was the Territorial Development of the United States with special reference to its constitutional aspects. This subject was selected for study because it was believed capable, if rightly studied, of furnishing the student with a background for the intelligent consideration of the questions of territorial expansion and government which the late war has made prominent and vital. For this purpose the work naturally fell into two divisions. The first part of the course was devoted to tracing step by step the growth of the United States territorially, from the founding of the English colonies until the present time. Here the whole emphasis was laid upon the fact that the United States has been an expanding, growing country from the first—that it has always held and administered territories—and with each step in this process of growth it was attempted to make clear what were the vital forces bringing it about. The second part of the course was devoted to the constitutional aspects of the administration of the territories, and this second half of the course was likewise treated under two heads. It was first attempted to discuss as fully as possible what was the basis in Constitutional Law, as interpreted by the Supreme Court, of the right to acquire and govern dependent territory, and second what has been the actual practice of the United States government in the acquisition and government of such territory. From the nature of the subject no text book was possible, and in some parts of the work even secondary works were not to be had. The subject was presented therefore in a series of informal lectures, based as far as possible upon a study of the sources at first hand. The class took careful notes throughout. At every stage of the work, however, the members were referred to the sources and to the best secondary accounts, for work on special topics, and the lectures were constantly interrupted for discussions which sometimes occupied the entire hour. Formal papers were sometimes prepared by the students, and frequent review of their lecture notes was tested by semi-monthly written examinations. It is believed that the entire class has a good knowledge of the history of the expansion of the United States, of the law and practice of the United States in the government of its territory in the past, and, consequently, a firm grasp of the questions involved in the possession and government of our new dependencies. This course has been of value, therefore, not merely in increasing th general knowledge of the students, but has all along had, as one of its principal aims, the direct practical advantage on such knowledge.

For this course the library has some excellent material. The debates in Congress and the Supreme Court reports have been of special help. The greatest deficiencies were felt to be the following: (1) There is no complete set of the Statutes of the United States in the library, though, as a depository for the government publications, it would seem that such a set should be here; (2) The Supreme Court Reports are not complete. There are in the library 126 volumes of the original reports, in 31 books of the L. C. P. Co. edition. It is believed that the Department would be greatly benefited could these reports be completed to date. (3) Reliable histories of the States carved out of the old Northwest Territory, of Florida, of Louisiana, of California, of New Mexico, of Oregon, and of Alaska would have been of service in the preparation of the lectures for this work.

On the whole it is believed that the work done and the interest shown in the Department of Political Science and History during the past year, clearly demonstrate the value of such work, and the interest which the College itself has in its future development.

Respectfully submitted,
CARL BECKER,
Instructor in History and Political Science.

State College, Pa., May 30, 1900.

# IX.—INDUSTRIAL ART AND DESIGN.

To the President:

Sir:—There seems to be but little that is new to write concerning the work of the department during the last year. It has steadily followed the prescribed course with varying degrees of success.

The number of students taking the work is greater than that of any previous year, but they have not brought so good an equipment for it, which has made the work more labored.

About 97 per cent. of our students have not had any training in Freehand Drawing when they enter, and a large proportion of those who have had it have been taught, if not in an indifferent way, by instructors who have had poor or insufficient training. The students have, consequently, established habits which interfere with easy progress until overcome. This condition of affairs necessitates our close adherence to elementary work. But, as careful training in elementary work of any kind is of the greatest value, we can afford to put our best into it, hoping to develop the higher with comparative ease when the opportunity offers.

We have hoped to have the work of the department partake of the nature of that of a good school of industrial art—fostering the ability to do with the hands that which the mind suggests of all that is useful and beautiful; which, to be worth while, does not presuppose the necessity to follow such work as a profession, for it will prove of much value to the men and women who use their hands, and will add refinement of taste in every direction for those who are trained in it.

The attempt to do a thing brings us to something of a realization of the value of the work of others, for, the mere on-looker is apt to believe things are easy to do because they appear so. Proper appreciation, then, of all effort is what the world craves, the individual longs for.

In the re-arrangement of the work for the year for all courses, it has been found practicable to give several hours per week in this department, in each of four courses in the second session of the Sophomore year. This increase of time should improve the character of the work. The scheme under this rearrangement is as follows:

### Sub-Freshman Class.

First session—5 hours per week.
Second session—5 hours per week.

### Freshman Class.

First session—2 hours per week for all except Course in Agriculture.

Second session—4 hours per week for Course in Philosophy; 2 hours first half of the session, 4 hours second half of the session for Course in Agriculture; 6 hours first half of the session, 4 hours second half of the session for Course in Biology.

### Sophomore Class.

Second session—3 hours per week for the courses in General Science, Latin Science, Classical, and Philosophical.

Some provision is also made for elective work in the general courses during the Junior and Senior years, and if these courses prove attractive to students, I should be glad to be permitted to outline a complete course of study, including recitation and practicum in Industrial Art.

The department is greatly in need of new drawing boards. Those in use were well-seasoned, but of soft wood, not such as draughtsmen require; and constant use for nine years has brought them to a condition unfit for designing, which involves more or less mechanical work; and tack holes and dinges furnish a very indifferent surface as a backing for any drawing.

The curtains need replacing, the tables redressing. Walls and floor are in bad condition, the result of nine years' wear and not abuse. The boards will probably cost about $100, but $150 should pay for boards and put the room, No. 274, in repair. We have never had a filing case or place for keeping free from dust the drawings of the students which have been retained as illustrative examples of the work of the department.

This should be provided at the earliest possible day. Such illustrations are especially useful to students just beginning a course in drawing, besides forming a creditable collection for exhibition at any time.

Respectfully submitted,
ANNA E. REDIFER.

State College, Pa., June 1, 1900.

# X.—LATIN.

To the President:

Sir:—I have only pleasant things to record since my last report and but one regret—that the department is not stronger. The usual routine work, with but slight variations, has characterized the last four sessions. It has been good in intent and not without good fruits, for though our students are few their character and spirit are good.

The work of the Sophomore Class, for the session now closing, has included a somewhat wider range than usual. We have read many of Pliny's letters, some of the best of Cicero's, and have made comparison of these with some fine English and other examples, such as Cowper's, Madame de Sévigné's and others. We have followed up, to some extent, hints given upon contemporary Roman life in the days of the Empire. The Tacitus read by the class in the Fall Session included selections from the History and the Agricola, together with the Germania as sight reading. The De Officiis of Cicero, read in the winter, included all of book third and fully one-half of book first.

The work of the Freshmen has been as scheduled—Livy in the fall, De Senectute in the winter, and Horace in the spring session. The class, during the winter, nearly completed, in the class room, the entire Cataline of Sallust, which was read at sight. In Horace, selections were taken freely from the Odes and one or more from the Epodes, Satires and Epistles. The peculiarities of Horace were studied and each ode or other selection was studied metrically and scanned orally. The increased interest of the most intelligent students shows that "the classics" so-called, can still awaken and sustain a profound interest even in the reader of our times. The thing recorded here with most pleasure is, the fact that, at length, we have been able this year to formulate a full classical course of four years. It is a consummation which should cause deep thankfulness to those who have the interests of our College at heart.

It is consistent to suggest at this time how such a course may receive permanent strengthening and assurance of growth.

First, by keeping the requirements for entrance as high as they are for admission to any college in the land. Let it be understood that no student can enter upon the Classical Course at State College who has not studied Latin at least four years and Greek three years. Or, in other words, let it be understood that he has read the amount of Caesar, Virgil and Cicero, of Xenophon and Homer, or their equivalents, which is required for entrance to the best colleges; that he must be able to read easy Latin at sight; that he has had four years close discipline in Latin Grammar and three year in Greek Grammar, or that he has done the amount of work in those studies which is usually not compassed in less than that time; that he has had Latin and Greek prose composition at least a year each; that he is familiar with Classical Geography, with Greek and Roman Mythology, with Roman History in its elements to the days of Marcus Aurelius, and with Grecian History to the death of Alexander. If we can secure at least this we shall lay a very large part of the basis of a liberal education and shall pave the way for much more rapid and varied work in College, the pace being now too slow because of lack of elementary knowledge.

Second, we must do good work. The direction which is given, the inspiration which is aroused must be as good here as it is anywhere. The persons in charge must be so thoroughly at home and at ease in the elements of what they teach and so filled with material that will illustrate and enliven what is taught as to carry authority on all matters, small and great, pertaining to the work prescribed in their department. They must be able to unravel the snarls. They must prove that the hard places are the richest. They must speak with easy masterfulness on all matters which they teach. They must be much more than schoolmasters. There are magnificent under currents of manliness and suggestions for culture in the Greek and Latin authors. These they must be able to point out. They must brush the dust from antiquity and burnish it until they reveal a life surpassing the best among the moderns. They must help the eager mind to understand what is hardest, teaching it that getting the ore of what is best out of a hard passage in an ancient classic, while it is attended with some of the difficulties that await the man who is going to the Klondike, is also attended with the same satisfaction. If that is not gold to the touch or to the sight, it is gold to the thought, which is far better.

Third, we must keep strengthening the course and gradually adding to our means of enriching it. Our library is now very helpful. The mythological, the artistic, the geographical, the archaeological, the historical sides of our work we have already good means to illustrate. We are adding to them and adding wisely. We need to collect slowly and, as we can, a complete set of Greek and Latin texts. Such a set is constantly needed by the instructor. Furthermore, our faculty is composed largely of classically educated men. Such a library would be found in frequent use.

Fourth, we must wait. A college is longer lived than any man. We must stand on the ground which has been specified. Great things, things that have durability of life are slow at the start. but in the end we have the elm, the oak, the olive, the sequoia. Let us build with a slow and enduring patience, as well as with truth and spirit, then strength will come to the department.

It is a department which should strengthen and give the key-note to all the work of the College. In order that this may be, the head of the department is willing to do all possible, and from what he knows of your own attainments in, and love for classical studies, he is sure it will be no fault of yours of we do not soon see all the barriers burned away.

With many thanks to my colleagues and to yourself for another year pleasantly spent. I am,

Respectfully yours,
BENJAMIN GILL,
Professor of Greek and Latin.

State College, Pa., May 16, 1900.

# XI.—LIBRARY.

To the President:

Sir:—Three factors are potent in determining the extent and the quality of the influence exerted by a library.

First, The number and nature of the books upon its shelves.

Second, The facility with which their contents may be consulted.

Third, The richness or barrenness of the mental soil with which it comes in contact.

To base a claim for approval upon the number of books acquired is to assert that they who read "To Have and to Hold" under the shadow of the "Narrative and Critical History of America" must be blessed by some adumbration at least of historical truth.

Yet without books we are nothing, and the library has shown its appreciation of that fact by adding since January 1, 1899, 2506 volumes. Of these, 1,549 are Government and State publications, 304 technical books for use in the various departments, and the small remainder, works in history and general literature. Among these are twenty-eight volumes of African history and travel purchased for the benefit of the students taking part in the debate with Dickinson College.

Of the department books, 87 are mechanical, 63 chemical, 52 mining, 46 civil engineering, 46 electrical, 10 physical, 10 biological, 7 mathematical, 5 botanical, and 3 psychological.

Three hundred and thirty-seven volumes of magazines have been bound and placed upon the shelves during the year, including 98 which belong to the engineering department.

The library has been fortunate in receiving a liberal donation of books and bound magazines from General Beaver, and has also been the recipient of a valuable gift of books, including a number of bound volumes of the "Atlantic" from Professor Alfred Smith, of Chicago, who is an alumnus of the College.

Some valuable additions have been made to the collection of reference books. Among them two five year volumes of the "American Catalogue," which now lacks three volumes only of being complete, "Warner's Library of the World's Best Literature," thirteen volumes completing the set of "Appleton's American Encyclopedia,' and Larned's History for Ready Reference."

In this connection I would express my earnest desire for the completion of the English "Dictionary of National Biography," of which we have now only nine volumes.

The number of books purchased has, of course, been limited by the amount of money at the disposition of the library, but with regard to the quality I may say that expressions of pleasure at the selections made have become very frequent from visitors whose good opinion we value.

Such expressions help to reconcile us to the unspoken protest in the face of the student who wishes to read Scott or Thackery or Stevenson and must be denied.

The additions have been largely in the line of history. Continued effort is being made to complete the sets of Government publications, especially to obtain the earlier issues, some of which are invaluable in the study of the history of our country. These, as far as they can be supplied by the Document Office, come to the library as a Government depository. There is another class of publications equally desirable, but not equally accessible. I refer to the issues of historical societies. The library is unable to obtain these by gift from the societies, and I make the suggestion that any influence which would give us the key to them would be highly appreciated.

There are frequent complaints from those engaged in historical study that the library is deficient in reproductions of the original sources of American history. The only collection of value thus far acquired is the set of Stevens's Fac Similes donated by Mr. Carnegie which is now completed and has been housed in a case suitable for its accommodation in the reading room where it may be freely consulted. We are yet without the "Jesuit Relations," and our resources for original research are in all directions very meagre.

The second point in question, the facility with which the seeker and the thing sought may be brought into contact, is a matter upon which much thought and effort have been expended. The library of a college is by no means an independent agency. Its sphere is so far co-extensive with that of the department class work that it can claim little single handed accomplishment. It is therefore its endeavor to co-operate as helpfully as possible with the other educational agencies of the college. Reference lists are posted for the various class requirements, from Freshmen briefs to Junior debates, and upon every imaginable subject from Shakespeare to sugar. We are glad to note a more intelligent use of the indexes by the students, and a desire on the part of some of them at least to handle them independently.

More satisfactory than the ability to help is the fact of being asked for help.

It is with modified pride that I make the statement that never within the period of the present administration has so much been expected of the library as now, never have so many wants been met or so many left unsatisfied. Many libraries are now publishing bulletins containing lists of books purchased and also reading lists upon special subjects.

The name of our library has been placed upon the mailing list of a number of such institutions and we have found the bulletins of value in our reference work. It is our desire to issue, when there is time for its perparation, an occasional bulletin of similar character which may be of use in exchange.

It is our constant aim to make the catalogue as serviceable as possible, and by the testimony of those going from us to other institutions, or vice-versa, we judge that it compares favorably with those of other colleges.

The author catalogue has been recently revised with a view to bringing it into condition for copying upon larger cards, as we look forward to the time when a more generous endowment will make this possible.

The third condition to be considered is one for which the library is not responsible, but there are indications, unmistakable to a close observer, that the interest in books is not limited to those whose perusal is necessary for the preparation of prescribed class work. There is an eagerness for the coming of the daily papers also and an intelligence shown by the students in discussing their contents that would justify a much larger expenditure upon newspaper subscription. The reading room has at present only three dailies:

The number of volumes now in the library is 16,511. The periodicals subscribed for number 95. A number of book reviewes were added to the periodical list at the beginning of the year. There has been a frequent call during the winter for articles on astronomical subjects. The magazine covering this field, to which most frequent reference is made in our indexes is "Popular Astronomy." I suggest that it be included in our list.

The average daily attendance in the reading room during the year has been 98. The largest attendance in one day 141. The loss of books during the year has been less than usual; that of the engineering library is but one book from each department.

An improvement has been made in the case of the theses. A record book has been purchased in which each thesis is entered by author, year and title, and an index has been prepared. The theses are filed alphabetically in pamphlet cases where reference can be easily made to them. It is to be regretted that they are not all provided with a substantial binding of a sort that would make it possible to place them upon the shelves and make them a part of the catalogued library. Many of the early theses were not deposited, and we should consider it a favor of any alumnus, who has his thesis in his possession and has not deposited a copy, would send one to be added to the file.

The work of indexing and arranging was done with great care by Miss MacDonald.

The pamphlet portion of the library has outgrown the limits of the room allotted to it and has overflowed into the public document room where it must soon again be crowded out by the documents which come in very rapidly. There is great need of a larger sized room devoted entirely to this purpose.

Two new book stacks were set up in the book room at the beginning of the college year. The capacity of these is very nearly exhausted.

Not the least important or the least costly of the things required in the library are the furnishings. The carpet in the reading room shows unsightly evidence of much wear and the shades have almost lost their serviceability. Shades are much needed also in the document room, where the strong light yellows the papers there on file. Some renovation will soon become imperative unless the acquisition of a new library building relieves the situation.

I wish to express my appreciation of the consideration shown me during the year, both by those who have used the library, and by you to whom I am responsible for its care. The evident purpose to further its interests in every possible way has been a great stimulus to my own endeavor.

My acknowledgment is also due to Miss MacDonald, my Assistant, for her sympathetic and efficient co-operation.

Respectfully submitted,
HELEN M. BRADLEY,
Librarian.

State College, Pennsylvania, May 24, 1900.

# XII.—MATHEMATICS.

To the President:

Sir:—I have the honor to present the following report for the Department of Mathematics:

The year just closing has been marked by certain changes in the work of this department, which have received your approval in prospect and which I believe give promise for the future.

Before referring to them, however, it is proper to say that the regular classes in Mathematics have been held. The same division into sections was maintained, in spite of the fact that the large number of men entering the freshman class last fall made some of the sections so large as entirely to overtax the board room at our disposal. It is not unlikely that six sections may be required in the fall.

The work of the instructors in mathematics, has, I believe, been faithfully and efficiently performed; and with less interruptions this year than last. At the opening of the College year Mr N. C. Riggs was engaged to do the work done by Dr. Benedict. Mr. Riggs has shown himself to be faithful and efficient.

The new schedule of studies contains certain improvements which affect this department. The courses have been differentiated from the outset with special reference to the needs of a student taking a technical, a general, or a mathematical course, so that students will receive equivalent but not identical training in mathematics.

The high standard of admission is very wisely retained and should be made to include Solid Geometry for Engineering Students as soon as possible.

Several new volumes have been added to the library. The need for them, which has been very great, will not equal the use which will be made of them. It is to be hoped that it will soon be possible to thoroughly equip this part of our work.

In closing this report, may I express to you, Mr. President, my sincere thanks for your patience and consideration for our work.

Respectfully submitted,
J. M. WILLARD,
Professor of Mathematics.

State College, Pa., May 24, 1900.

# XIII.—MECHANICAL ENGINEERING.

To the President:

Sir:—The work of the past year in the School of Engineering has been characterized by attainments as satisfactory as possible under discouraging conditions. The interest shown by the students in their work has been marked, and the efforts put forth by the instructors have been earnest and unflagging. The outcome is gratifying and surprising, when it is taken into consideration that the teaching force, already doing more, or as much as should be expected of them in justice to themselves and their work, was further reduced. As it was impossible to give the instructors many more hours of teaching than they had had before, this reduction in the force made it necessary to increase the sizes of the sections taught by each instructor; in some cases, notably in drawing, making them almost twice as large as could be taken care of properly.

The following table giving figures relative to drawing and shop work (which are taken by all students) compiled from data obtained by personal correspondence with the Institutions mentioned, is of interest in this connection:

| Institutions. | Number of students in engineering. | Instructors in | | Percentage of engineering students in total attentance. |
|---|---|---|---|---|
| | | Draw. | Shop. | |
| Cornell University, | 754 | 15 to 20 | 12 | 33 1-3 |
| University of Cal., | 729 | 4 | 3 | 21 99-100 |
| Mass. Institute of Technology, | 535 | 4 | 6 | .............. |
| Purdue University, | 450 | 4 | 7 | 42 |
| Ohio State University, | 330 | 5 | 4 | 32½ |
| University of Wis., | 328 | .............. | 7 | 17 |
| Iowa State College, | 311 | 3 | 3 | 35 to 40 |
| University of Ills., | 287 | 3 | 4 | .............. |
| University of Mo., | 214 | 3 | 4 | 10 |
| The Pennsylvania State College, | 209 | 1 | 1¼ | 74 Col. |
| University of Minn., | 208 | 2 | 2½ | 24 |
| University of Me., | 195 | 3 | 3 | 60 |
| University of Tenn., | 192 | 1 | 3 | 25 |
| Sheffield Scientific School, | 190 | 6 | .............. | .............. |
| Lawrence Scientific School, | 189 | 4 | .............. | 33 |
| University of Pa., | 161 | 2 | 2 | 15 Towne<br>4 Univ. |
| University of Kans., | 156 | 2 | .............. | 33 |
| Leland Stanford University, | 148 | .............. | 3 | 18 |
| Washington University, | 145 | 1 | .............. | 44 |
| Case School of Applied Science, | 106 | 3 | 6 | .............. |
| Colorado Agricultural College, | 101 | 2 | 5 | 27 |
| University of Vt., | 72 | 3 | 2 | 25 |
| Clemson Agricultural College, | 56 | 2 | 4 | 20 |
| N. Dak. Agricultural College, | 31 | 1 | .............. | .............. |
| Md. Agricultural College, | 30 | 2 | 2 | 25 |

It will be seen that no institution having as many engineering students as The Pennsylvania State College, has fewer than two instructors in drawing, and many institutions having a smaller number of students, have three or four instructors. We have but one and he is obliged to give instruction in other subjects, as well.

In the shop work the disparity is even greater than in drawing. Out of twenty-five colleges, having Engineering Courses which include shop work, not one has fewer than two regular instructors, although the number of students in sixteen of them is smaller than our number and in one at least there are but thirty. Our shops are given one instructor and a quarter, one regularly, and one taken from the working-plant force of the Institution. About one-fourth of Mr. Emerick's time, as much as he can spare from his regular work, is given to this instruction, and probably covers all that he is prepared to give. Cornell, with less than four times as many engineering students, has twelve instructors—about eight times as many as we; Purdue, with about twice as many students, has seven instructors—over four times as many as we; Ohio, with less than twice as many students, has four instructors—three times as many as we; Maine, with 195 students, has three instructors; Case School of Applied Science, with 106 students, has six instructors; Tennessee, with 192 students, has three instructors; Wisconsin, with 328 students, has seven instructors; University of Minnesota, with 178 students, has two and one-half instructors; The Pennsylvania State College, with 209 students, has one and a quarter. Not one of these schools gives a more extended shop course than ours, unless it be the Case School of Applied Science.

Permit me to say, at this point, Mr. President, that these comparisons are not made in a spirit of criticism or complaint. It is well understood that the work has been afforded the best conditions possible, under the circumstances. However; I believe that it is important that the effect to be anticipated as a result of our limited circumstances be fully recognized at this time.

The institutions quoted are among those with which we have to compete. With smaller teaching force than the least of them, we must do the same work and do it, too, with students who come to us less well prepared for entrance than those of many of the similar schools. On this account we should be able to give more, rather than less, personal attention to our men.

The number of our engineering students is greater now than it has ever been before, and unless there should be a decided falling off in the coming year, it will be impossible to give the instruction the courses provide for, with the present teaching force.

Next to favorable conditions of admission and teaching force, the rank of an Engineering Institution depends upon equipment. In order to keep our stock on hand in good condition and to add the appliances which will familiarize our men with the latest and best invention and usage of the times, it is essential that a considerable fund be devoted annually to this end. During the past two years there has been no appropriation for this purpose and, though the laboratories have not deteriorated seriously in that time, it will be impossible to keep them up to the requirements of the work through a longer period.

We have secured an enviable reputation in our engineering work, and in order to maintain it we must do work that will compare favorably with that of other institutions. We have, perhaps, been holding our own in the immediate past, but it is essential that we do more than maintain the past standard. It must be borne in mind that if we do not steadily advance, there is sure to be a retrogression, a condition which I do not believe that this institution can afford to permit in her Engineering School.

Because of the nature of its founding, because of the character of its large and valuable equipment, and because of the needs of the young men of Pennsylvania, this is and must continue to be in the main a technical institution. The rapid development of manufacturing industries has caused calls for engineering graduates to be more imperative to-day than ever before and the time has arrived when the industrial world, quite as urgently as the professional, demands the thoroughly trained worker. It is recognized that progress and development depend upon his effort. Where there was formerly one man, fitted by natural aptitude and years of experience, to develop a given line of work, the technical institution now provides many, and the consequent activity and competition have brought about not only greater proficiency in every direction, but the opening of new industries. The Engineering School of The Pennsylvania State College has received more calls for men this year than ever before. The importance and responsibility of the positions which are filled by her graduates may be appreciated, in some measure, from a glance at some of the titles they hold. Among them are general managers, managers and superintendents of light and power plants, signal engineer for railroad company; pneumatic and electric signal erecting engineers; heating and ventilating engineers; chief draughtsman for railroad company; superintendent of wires; inspectors of conduits and cables; erecting engineers for machine builders; consulting engineer; expert engineer for manufacturing firms; tool manufacturer; mining engineers, designers and draughtsmen of various degrees from chief down; engineer in charge of motive power for railroad; engineer for telephone and telegraph companies; engineers for railroad company, for land company, for cement company;

foreign representative for an automobile company; editors of engineering papers; professors of engineering, etc., etc.

A further idea of the value of their services may be gained from the fact that many of our younger men are receiving salaries ranging from $1,200.00 to $3,500.00 and at least one alumnus of no more than thirteen years' standing was recently called to a position at $13,000.00 a year.

Although, as has been said, the Department of Mechanical Engineering has been short in quantity of help, it has not been lacking in quality. Of my assistants it may be permitted me to say, I trust, that during the past year, I have been impressed with the increase in wisdom and facility which has come to them with passing years. So far as improvement in the work of the department is dependent upon their efforts that improvement is apparent. The thoroughness of the general training, the excellence of the methods pursued, and the nicety and correctness of finish in all preserved work must be evident to the most casual observer, if he but devote sufficient time and attention to inspect the results which have been attained during the past year. In shop and laboratory work, in drawing and design, an unusual enthusiasm and zeal on the part of the student have attested the devotion and skill of the instructor.

The course of study is conducted on practically the same lines as those presented in previous reports, though improvement in methods and means is continually sought and attained. The effort is made to provide for the applicant for the degree in Mechanical Engineering, a comprehensive, practical and available education, such a course of study as should enable him quickly to adapt himself to the requirements of business life, and at the same time afford him an impetus toward further expansion of his powers. If his growth is to end with his college education his time has been ill spent. That success has attended this aim to prepare men for future, as well as present development may be seen from a review of the records of graduate students. It may be said without exaggeration that, taken as a whole, they are a set of men of sterling worth and exceptional ability.

An especial effort is being made to keep in close touch with the alumni of the department. By the present method of communication with them we are not only kept acquainted with the character of the work engaged in, but with all questions of importance relating to it. Having learned, by this means, the kind of experience they have had, the salary and other conditions of their present employment, and the circumstances under which they might desire to make a change of position, it is anticipated that it will frequently be possible to assist them to secure more promptly the kind of work for which they are best fitted. It is interesting to note, in this connection, that a State man who is already established, is always glad to employ or recommend a fellow alumnus, and the result is that in almost all business centers or large firms where one State man has been employed there are shortly a number of them to be found.

The department has been fortunate in being able to secure during the past year or two some valuable additions to its equipment by donation. The Westinghouse Air-Brake Company and the New York Air-Brake Company have each presented complete sets of air-brake equipment for a locomotive, a passenger car, and a freight car.

The Detroit Lubricator Company, the Powell Company, the American Steam Packing Company, and others, have presented samples of their products. All of these donations are excellent experimental and illustrative appliances, their commercial value amounting, probably, to about $800.00.

## Apprenticeship Course.

After mature deliberation on the subject of an Apprenticeship Course for The Pennsylvania State College, I desire to make the following recommendation: That an Apprenticeship Course in shop work be offered to six young men, the applicants to be not less than seventeen years of age and to have such preparation as would enable them to enter the Sub-Freshman class. The understanding with these applicants to be that they would be given a full shop course with some drawing, but that no definite order of work would be followed, and that they would be obliged to give such assistance from time to time as might be called for from them; all this assistance, however, to be in line with their apprenticeship course. They would be expected to spend eight hours a day, at least, in the shops, and should be accepted only in case it is their purpose to continue the work a year or more. No fees should be charged them, as their services would be of sufficient value after a short time to compensate for materials used. Their selection to be by competitive examination, those having the better preparation being given the preference.

With such apprentices in the shops much repairing and building of special equipment for shops and laboratories could be accomplished at a minimum cost; general assistance in the preparation of materials and other work could be given by them to the regular instructors, and after a certain advancement had been achieved, aid might be had from them in the instruction of classes. Furthermore, I believe that this policy would be helpful to the regular students in their relation to the shop work. The fact that the shops would be continually in operation, appliances of various kinds being under construction, would promote interest and might frequently afford valuable lessons.

For a State Institution, in addition to the advantages already enumerated, there is another reason, an important one, why some such system should be introduced. We have a considerable equipment of costly appliances, which is State property, here for the sole purpose of giving instruction. If this equipment can be used to give a better preparation to young men who are unable to go to College, for their work in life, without interfering in the slightest degree with the higher educational work for which it is primarily designed, it seems to me a desirable end to bring about.

It is possible that six apprentices would be too large a number to begin with; if so, this number might be reduced to four or three. Professor Towle, who has accomplished so much in our shop work and who has had wide experience in manual training and manufacturing, agrees with me in believing that the introduction of such a system would be advantageous.

## Steam Plant.

As the current expense of maintaining the steam plant is necessarily large, it is exceedingly desirable that everything possible be done in its management to reduce costs. A long step in this direction might be made by the adoption of some system of automatic regulation of the heat supply. Anyone familiar with steam heating appreciates how difficult it is to regulate the temperature by closing and opening valves by hand, and that it consequently is more frequently regulated by opening windows. It has been estimated that in many cases, one-third of the heat of the fuel is wasted. In the small dormitories heated by a large system the loss is probably greater, due to the fact that even with closed radiators the heat reduction is not sufficient and windows must be opened in order to make the temperature bearable.

An automatic system, that of the Johnson Temperature Regulating Company, was installed experimentally during the past year, at practically no cost to us, but at considerable cost to the firm, in several of the College rooms. This sample plant has demonstrated that the company's guarantee that the temperature shall not vary over one degree from that desired, may be relied upon.

Through correspondence with a number of people in whose buildings this system has been in use it has been learned that in all cases the heat regulation has been eminently satisfactory, and that there has been a probable saving of thirty-three and one-third per cent. in fuel. The saving to us would not be so great as it would not affect the heat losses in transmission, but it would be very large.

Both from the point of view of economy, then, and from the gain to be had in conditions conducive to health and comfort, it is extremely desirable that this system be introduced in the College buildings.

The introduction of coal and ash conveyors (described in past reports), would affect the further annual saving by reducing the labor. Estimates of the cost of installing these devices are given in a supplementary report.

In closing this brief statement of conditions relating to the School of Engineering in general, and the Department of Mechanical Engineering in particular, permit me, Mr. President, to thank you for your cordial interest and sympathy.

Respectfully submitted,
LOUIS E. REBER,
Professor of Mechanical Engineering.

State College, Pa., May 24, 1900.

# XIV.—MINING ENGINEERING AND GEOLOGY.

To the President:

Sir: Allow me to hand you herewith a report of the Department of Mining Engineering and Geology for the Collegiate year 1899-1900.

Few events have transpired and there is little of interest to report other than to indicate the opportunities lost because of the enforced retrenchment which the Department has been compelled to adopt. The meagre allowance to the Department being insufficient to provide for salaries and contracts previously made, no purchases were concluded other than those absolutely indispensable. Outstanding bills amounting to $45.70 were paid. The expense of maintaining the Assaying instruction reached $147.82 for the present Senior class; $270.30 were consumed in settling the accounts for printing the Mining Bulletin and announcements, from the contracts for which we were released by the publishers as soon as practicable. The Department's share in the maintenance of Library, Laboratories, and care of rooms for the year was $191.05, including the needed repairs to machinery and apparatus. The engagements for salaries and field work, with the necessary outlay for analyses and the compilation of reports consumed respectively $3,942.72 and $558.55. Some of these items are of prior contracts which are no longer in force. The filed work and reports upon the building materials of the State, for example, which must be abandoned, will not further enlarge the deficit. Attempt was made to dispense with every laboratory and incidental expense, but even with the reduction in the teaching force the maintenance exceeded the allowance for the year.

The work which formerly had been performed by four instructors was reduced to the compass of two teachers. The retirement of two members of the corps being accepted with extreme regret, not only because efficient and successful teachers were dismissed, but becaus the attention of the remainder of the corps was dissipated over many branches of instructional work, the services of Dr. F. J. Pond were called into further action. He assumed charge of the classes in Metallurgy, and those in Crystallography and Mineralogy were assigned to Dr. W. J. Keith. The classes were conducted as formerly without any impairment of the character, scope or extent of the instruction in the several subjects: and while we may congratulate ourselves in having had these gentlemen to aid the Department in its present dilemma, the assignments could hardly be regarded as other than temporary. Faithfully as the work was accomplished, still it must be without the enthusiasm which a regular employe might display in planning for the future; the result inevitably must be detrimental to the Department. Such a transfer of teaching force involves, too, a duplication of curatorial labor; for according as the scientific or economic phase of the subject will appeal more strongly to the teachers, so will his treatment of the subject vary with that of his predecessor and a redistribution of the museum materials, be made. This invites considerable labor which is repeated by the next incumbent. Except for the transposition of a few subjects in the curriculum rendered necessary by the proposed division of the collegiate year, there were no changes in the schedule.

Liberal contributions of blue prints, catalogues, fossils and illustrative materials have been received during the year and duly acknowledged. If room could be had for the placing of machinery and apparatus, it would have been possible for us to accept a number of appliances which would be of great value to the Department. The number of exchanges from surveys, societies and inspectors have somewhat diminished since the discontinuance of the publication of the Mining Bulletin.

The summer school for the coming season will be held at Windber, Greensburg and Latrobe; these places being selected as central for the members of the class and as affording the widest scope of information for the service of the two ranking sections. The authorities of the former mine, which is the largest in the world, have generously extended us courtesies beyond our expectations. Last summer under the charge of Assistant Professor N. W. Shed, the classes visited Pottsville, Lebanon and Steelton, studying the coal and iron industries of these regions.

During the past year more than a hundred applications for analyses and opinions have been received and replied to. The increase in the number of these requests for information during the past four years, is a demonstration of what has been claimed in previous reports, i. e., that there is a demand for such information and that the College could serve the citizens and industries of the State to a very marked degree. The information furnished is fruitful of results in exploration, or saves the inquirer from needless expenditure. Every dollar wrested from the soil by agricultural or deeper mining efforts contributes to the welfare of the nation, and increases the circulation of the materials for the arts and conveniences of life. And in no small degree, therefore, does the effort of this Department, in common with the Agricultural Department of the College, aid in the circulation of valuable information. Nowhere else in the State is located any official to whom requests for information or advice may be submitted, nor any one to whom may be made appeals for expert aid. And it is appropriate therefore that the College should become the authoritative Bureau. It has been, however, a matter of chagrin that the Department has had to confess its inability to make analyses gratis as before, or even to prepay postage, though every endeavor was made at all times to furnish other information as complete as was possible with the means at our hand. It is sincerely hoped that this embarrassment may be spared us during the coming year. It is inferred that the coming summer season must pass by without any effort at field work as heretofore, and it is hoped that on account of the amount of data which has accumulated, it will not be deferred long.

It is possible, of course, for this Department to continue to conduct its affairs with some measure of success, upon the current basis, with the present equipment and the present allowance of space, but an enlarged appropriation is absolutely essential if one is to maintain even the present machinery in proper condition. And more than ever has this fact become apparent since the reduction in the teaching force. The museum and laboratories are scattered through four buildings on the campus and in several rooms in each. Among these the instructors must circulate in maintaining classes, transporting specimens, supervising laboratory work, and aiding the research work of the upper class men. While this was somewhat effectively done by the former corps, it has become a matter of serious inconvenience to the present instructors. Being the last comer, the Department of course must accommodate itself to whatever room is available; nevertheless, it urges a recognition of its needs and reiterates this request for sufficient accommodations consolidated within one building. It is not a subordinate Department, but has a scope of work instructional, technical and industrial that requires room for its growth.

Notwithstanding these embarrassments it has made an impress upon the welfare of the State, and has a goodly share of attendance upon its course; and however gratifying it may be, it is not satisfactory, for there is no reason why this Department, in this College, in the greatest mining State of the Union, should not have a very large attendance of students. If a definite appropriation could be made for it permanent and secure, the plans for its expansion could be maintained and its clientele, impressed with its permanency. I can speak with praise and commendation of the excellent work of my aids in the Department, and also of the cordial assistance afforded by the others.

Allow me to extend to you the thanks of the Instructors in our Department and of myself for the continued encouragement, advice and assistance which have contributed so largely to our efforts.

Yours very respectfully,
MAGNUS C. IHLSENG,
Professor of Mining and Geology.

State College, Pa., June 1, 1900.

# XV.—MODERN LANGUAGES.

## (a) GERMAN.

To the President:

Sir:—Much of this report must necessarily be a recapitulation of the work as done and reported from year to year in the present regime of the department, covering a period of five years, during which no material changes of courses and instruction have taken place. There is, however, one gratifying and conspicuous feature of the past year's work that deserves special mention: it is, that within the range of our observation the scholarship and moral tone of the entering class have never been so excellent. Out of a class of fifty-three (53) in German, only five (5) failed in their first examination.

The number of students that before entering have had German sufficient to be regarded as equivalent to the first year's work in course is from year to year increasing, indicating that the time is soon coming when we may safely require one year of German for admission and thus make room in this subject for advanced work in all courses. Our curriculum for the engineering courses requires 185 hours of prepared work in French or German. The Massachusetts Institute of Technology requires both languages, 186 hours in each. Cornell requires for entrance the equivalent of our entire course, and 100 additional hours. These facts speak for themselves. It is earnestly hoped that a more liberal allowance of time can be made for these subjects.

A few words on the importance of foreign language study may not be out of place here. "Of what use is a modern language to the student in an engineering course who never expects to go abroad or have occasion for speaking, or even using, it in his reading at home? Why can not the time be given to some subject in science, for example, that would be of more direct value to him?" These are some of the questions under which a large percentage of our students chafe.

Foreign language study strengthens the memory, enlarges the resources of expression, requires efforts at comparison, discrimination, analysis and reflection, calls attention to the meaning of words, helps to form a good style, widens the mental horizon, develops aesthetic tastes, and gives a broader view of life. It furnishes one of the best possible means for close reasoning. The Report of the Committee of Twelve of the Modern Language Association makes this statement: "Grammatical analysis and synthesis, while less mechanical and more varied in their operation than elementary mathematics, are nearly or quite equal to it as a means of inculcating the habit of accurate ratiocination." It is generally conceded by educators that the modern languages when properly taught can furnish mental discipline as thorough and useful as can the ancient languages. The Report referred to above also contains this statement: "Difficulty can not be the highest test of educational utility, else Latin and Greek should themselves give way to Sanskrit and Chinese. Evidently it is the goodness of the kernel and not the thickness and hardness of the shell that we are mainly to think of. The kernel is the introduction to the life and literature of a great civilized people, whom it is, for some reason, very important for us to know about. And it may properly be urged, on behalf of the modern languages, that just in proportion as they are easier to acquire, the essential benefit of the acquisition is the sooner realized. They give a quicker return upon the investment." The literatures of France and Germany, next to that of the English language, have made the most important contributions to modern civilization. The profit, therefore, to be derived from the study of such literature can not be denied.

As stated in a former report, it is impracticable, within the limits of the time allotted, to accomplish much in the way of acquiring a speaking knowledge of a foreign language. To converse in such a language is an object of minor importance for several reasons. In the first place, as hinted above, such an accomplishment calls for very much more time than could possibly be given in a course leading to a degree, which, of course, includes the study of other subjects besides modern languages. Residence abroad or with cultured foreigners at home is the only practical, successful and speedy method for this end. Then again, even if sufficient time could be given in our college courses for this purpose, the opportunities for continued use of the language are so rare that in the vast majority of cases, the accomplishment so laboriously acquired is entirely lost through disuse, as in the case of the foreigner's own tongue after long residence among a people of a different language.

This does not argue, however, that the spirit of the language cannot to a considerable degree be imbibed, even within the narrow limits of the time allotted. How can the student be made to feel the force of what he is reading without going through the mechanical process of translation? This is the chief problem which the department has been trying to solve in its present administration, and the results show that success has attended the efforts of every student who has faithfully endeavored to do his whole duty. Space will not permit more than the merest outline of the methods used in the case of German.

Joynes-Meissner's Grammar forms the basis of all grammatical work. It is distributed so thinly and uniformly among the 185 hours of the engineering courses that ample time is given for absorption and practical application. After a lesson or two of drill in the alphabetical sounds and in the pronunciation of words illustrating them, the student is at once put to sight-reading in Guerber's Märchen und Erzählungen, a text-book particularly well adapted for the purpose. The sentences are short and simple, the words to a considerable extent correspond in form and meaning to the English, and the sequence of ideas is logical, so that the student grasps the meaning the moment he pronounces the German, and becomes interested from the start. The text is so graded that, as he advances, he meets with more difficult words and constructions, which, with his accumulated knowledge of preceding passages and a few suggestions from his instructor, he can readily understand. This exclusive sight-reading and translation in the reader is continued through 20 recitations and is accompanied with grammatical drill in nouns, adjectives, the conjugation of haben, sein, and werden, and with oral and written translation of simple sentences from English into German and vice versa. Special emphasis is laid on pronouncing the german sentences, one at a time, before they are translated. The omission of this feature is considered a serious mistake. The ear as well as the eye should be trained to convey impressions. This practice is kept up persistently throughout the entire course and goes far toward the acquisition of that Sprachgefühl so essential to success in the study of a foreign tongue.

At the close of this period of exclusive sight work the grade of reading text reaches such a degree of difficulty that assigned preparation and the use of the dictionary become henceforward necessary, though sight-reading is by no means discontinued. The student at this stage has become familiar with the peculiarities of word order, which is one of the principal difficulties for the beginner. The mastery of the German verb, the very backbone of the language, forms the chief theme of class drill for the next 40 lessons. Since it is chiefly the conjugated verb that shifts position in the German sentence, abundant drill is given in exercises like this: Translate in every tense of the indicative, "A bridge is being built across the river." Translate the sentence similarly in the interrogative form; also after a verb of saying, thinking, etc., introducing the clause by a subordinate conjunction. In this manner the three different verb positions are illustrated and every variety of verb construction is treated, such as weak, strong, mixed, modal, passove, separable and inseparable and those that may be either; those requiring sein and those haben; those requiring a modification of the usual transposed order; and those with dependent infinitives without zu taking peculiar forms in the perfect tenses. Thus two of the greatest difficulties of the language, the verb and the word order, are thoroughly mastered in the early stages of the course. This largely explains why our students in the first semester of the second year can read intelligently such difficult literature as Beresford-Webb's Historical German Reader and Dippold's Scientific German; and in the second semester, Freytag's historical novels and Schiller's dramas; and, during the Junior year, Goethe's Faust and Lessing's dramas, more than half being read in German only, or translated at sight.

By the time the student has reached the Junior year he is fully prepared to enter upon the study of German literature as such and through it into the intellectual life of other times and of another nation. The plan for study at this stage is this: In the case of the two parts of Goethe's Faust, from 75 to 100 lines are prepared daily for good English translation and comment. About 100 lines more are translated at sight, and some are read without translation when the meaning is clear. Unimportant parts are omitted. Each student is provided with a syllabus of questions and references to other works bearing on the subject. These questions he is expected to answer from his readings as directed by the instructor. It is to be regretted that this feature will either have to be continued only in a half-hearted way or be abandoned altogether, owing to the serious lack of suitable reference books, so much needed in this work. The department of modern languages can no more be expected to develop and do efficient work in the advanced stages of the course without a proper equipment of books than can the civil engineering, the mechanical engineering and the chemical departments without their instruments, shops and laboratories.

Grateful acknowledgement is made for the two excellent historical maps that were procured for the department early in the year.

Respectfully submitted,
CARL D. FEHR,
Assistant Professor in Charge of the Department.

State College, Pennsylvania, May 19, 1900.

## (b) THE ROMANCE LANGUAGES.

To the President:

Sir:—It gives me great pleasure in submitting this report, to call attention first of all to the renewed interest in the work of this branch of the Modern Language Department. The classes, this year past, have been much larger than usual, showing that the value of French for the student of Engineering is being recognized. During the Fall Session, the sections were so large as to crowd uncomfortably the room assigned, while throughout the entire year the seating has been much closer than is compatible with good work. It is to be hoped that this difficulty may soon be obviated.

The work with all classes has been reorganized this year, an attempt being made to form more comprehensive and systematic courses of study. The limitations necessarily attendant upon the brief period devoted to the subject by the Engineering student are recognized only too well. Consequently it has been the aim so to arrange the work that every recitation period may count for the most possible.

Considerable improvement was noticed in the class entering last fall with regard to their proficiency in the elements of English. Although their knowledge upon this subject was not so extensive as a college man should have, it was superior to that of many previous classes. Heretofore much valuable time, needed elsewhere, has had to be spent upon the fundamental principles of our own language. Great ignorance has been and is yet betrayed concerning parts of speech and syntax. More rigid requirements for entrance in practical English grammar, or a thorough course along this line, for Freshmen, would greatly assist the work done in every language department in this institution.

The course for the Freshman year, which is the same for the student of every department taking the language, has been made as practical as possible. The grammatical side is emphasized very carefully that a good foundation may be laid, but enough well graded translation is brought in to avoid dryness and keep up the pupil's interest. A great deal of reading in the original is done to familiarize the student with the sound and technicalities of the foreign words and accents. Frequent translation from English into the language studied is used as a helpful adjunct to facilitate the change from one idiom to another. Sight reading is also aften resorted to, as a useful method of testing the knowledge already gained. By means of conversation used as frequently as possible the student is accustomed to the sound of the strange language and gaining confidence, can express himself, slowly perhaps at first, in the unfamiliar tongue. It must be borne in mind, however, that no claim of making fluent conversationalists in French is advanced, since the medium necessary for such a result is lacking in this country where the vernacular is English.

In the Sophomore year the student is introduced to the field of history and science, greater stress naturally being laid on the latter. Specimens of scientific composition of all kinds are used in class that the pupil may have an acquaintance with all scientific vocabularies. Review of the grammar is also taken up by means of composition of various kinds, and, by dictation, the ear is trained as well as the eye. A thorough course in letter-writing is given in order to train the student in every style of correspondence from a polite note to a technical business letter. Although an attempt is made to teach every phase of the language, it must of necessity be superficially done in the time allotted, and it is hoped that ere long the study of the Modern languages may be continued through the Sophomore year by the technical students.

In the last session, Sophomore year, when the classes are narrowed down to the general courses the work takes a distinctively literary turn. A thorough knowledge of the history of the literature is given with the principal epochs and the epoch-making forces and writers. Extracts from all the best known authors of later centuries are read and discussed in class while their lives are commented upon and attention called to their influence upon the literature of their country.

The work in Spanish the past year has been very interesting and inspiring. There has been a greater demand than usual for it and two classes have been maintained, one beginning the language and the other doing advanced study. Both have shown great eagerness and it has been a pleasure to work with them.

An effort has been made to the give the instruction as practical a trend as possible since some of the students expect to be, another year, in countries where Spanish is the spoken language. Every method has been tried to aid the pupil in his progress. By means of copious translation from Spanish and from English, the language has been made familiar and the differences between the two idioms emphasized. Enough conversation has also been given to enable the student to get along under ordinary circumstances where Spanish is spoken. Fluency has not been striven for, practicability and utility being the only aim. Scientific works of various kinds have been read in prepared lessons and at sight to give the student a slight knowledge of all technical vocabularies. With the increased demand it is believed that this course will fill all needs and meet all expectations.

Because of the redivision of the college year, a rearrangement of the curriculum, beginning with next year, has been necessary. The work which so naturally fell into three terms must now be done in two, but no confusion is anticipated from a change of subject in mid-term. There will be a gain of time in the loss of one examination, though more ground must be covered in each.

By the new arrangement the general student gains much both in French and Spanish. He can now continue the languages, if he so desires, through the Senior year, thereby acquiring, together with a broad knowledge of the literature, a comprehensive view of the history of the languages and the rules governing their formation from the mother tongue. As it stands, a student can get as complete and thorough a course in these branches in The Pennsylvania State College as in any institution, scientific or classical, in this country. It is hoped that many will take advantage of these courses as the pursuit of either or both combines pleasure and utility to a remarkable degree.

In the advanced work great need of reference books is felt. There is a dearth of French and Spanish authorities in the library, and the teacher is obliged to depend upon the criticisms, often biased, in the text-book used. The Spanish Dictionary is out of date and a reliable one should be purchased. One or two good histories of French Literature ought to be on the shelves, as the student cannot afford to buy for his own use a complete and trustworthy edition. At present no reference work can be done through lack of the necessary material, and it is hoped that this difficulty will soon be removed, as much progress is gained from this kind of work. Twenty-five or thirty dollars judiciously expended would relieve the pressing need and greatly aid the instruction given.

Thanking you, Mr. President, for your unfailing support and helpful counsel, and each and every one of my colleagues for their universal consideration and courtesy, and my classes for their unflagging devotion to duty, I am,

Very respectfully,
IRVING L. FOSTER,
Instructor in the Romance Languages.

State College, Pennsylvania, May 21, 1900.

# XVI.—PHYSICS.

To the President:

Sir:—The topics of this report are:

1. Work of the Department for 1899-1900.
2. Condition under which work is done.
3. What is the proper grade of work.
4. Physics in Education.

## 1. Work of Physics Department for 1899-1900.

The several courses, 1 to 8, described in the Catalogue for 1898, 9, pages 60 and 61, have been carried on during the College year about closing in the following classes and practicums:

### Fall Session, 1899.

| | Hours work. | Number students. |
|---|---|---|
| Classroom: | | |
| Electricity: Gerard, | 4½ | 41 |
| Mechanics and Sound: Hastings & Beach, | 4 | 15 |
| Theory of Light: Preston, | 8 | 1 |
| Practicum: | | |
| Electrical Measurements, | 6 | 16 |
| Physical Laboratory, | 4 | 18 |
| Physical Laboratory, | 10 | 1 |

### Winter Session, 1900.

| | Hours work. | Number students. |
|---|---|---|
| Classroom: | | |
| Heat: Nichols, and Lectures, | 3 | 42 |
| Light and Heat: Carhart, | 4 | 15 |
| Light (Short Course), | 1 | 5 |
| Practicum: | | |
| Electrical Measurements, | 4 | 15 |
| Electrical Measurements, | 8 | 1 |
| Physical Laboratory, | 4 | 23 |

## Spring Session, 1900.

|  | Hours work. | Number students. |
|---|---|---|
| **Classroom:** |  |  |
| Electricity: Gerard, | 6 | 33 |
| Electricity and Magnetism: Hastings & Beach, | 4 | 13 |
| Theory of Heat: Maxwell, | 4 | 1 |
| **Practicum:** |  |  |
| Electrical Measurements, | 4 | 16 |
| Physical Laboratory, | 4 | 7 |
| Physical Laboratory, | 8 | 2 |

The numbers of students, though less in one or two instances, on the whole are greater than last year.

The work in all the courses, classroom and laboratory, has been substantially the same as for last year—given in considerable detail in my report one year ago. During the present session, to prepare for the revision of courses in semesters next year, Electricity has been given six hours per week (instead of three) and Wave Motion (three hours per week, same class) postponed to next year: and hereafter this latter subject will regularly come one year later in the courses.

Any considerable enlargement, or improvement, involving equipment, was rendered impossible by the action of the Legislature and the Governor, which left this Department among those without appropriation. As this condition will continue during another College year (practically), we shall suffer greatly.

Fortunately, arrangements were made whereby Prof. Garver remained during the year and I should greatly regret the necessity of losing his faithful and efficient services.

This is the second year Mr. E. H. Myers has served as assistant in the Physical Laboratory, his greater familiarity with the work and larger experience adding to his efficiency in that capacity. I shall be glad to have Mr. Myers continue this work, if he desires it, next year.

### 2. Condition Under Which Work Is Done.

I have spoken (in January Reports, wherein financial matters belong) of the economic results of neither having at any time in the existence of the Department a sufficient appropriation for a systematic equipment nor a certainty of any annual amount for a period of years that could be used in pursuance of a definite plan.

Without wearying with details of how and why, I wish to emphasize, by distinct statement in this Academic Report, that the above condition has also had very serious effects on the work done in the Department.

For the sake of the work, even more than for the financial economy, it is very desirable that, if possible, provision should be made for a considerable equipment at once and a certainty of some annual amount for a number of years in pursuance of a definite plan.

The past twenty-one years during which this has been a separate Department in the College has been a period of great revision, even of revolution or re-creation, in Physics teaching.

The great discoveries of Henry, Faraday, Joule, and others; the profound researches of Maxwell, Thompson, Helmholtz, and their great compeers in analytic thought; the general introduction of student laboratory work; the enormous expansion of applied physics in industries—these have so wrought upon and changed the foundations and substance of Physics and the relative values of parts thereof, that it has almost seemed as if the old Physics were passed away and there were a new Physics created. But, after all, there is a great body of the old Physics standing fast; though the foundations seemed to be removed, rather they were but lifted a little more out of the deeps of the unknown by the rising into the sea of knowledge of still deeper foundations. It is safe, I think, to make a pretty extensive plan, embracing a large amount with assurance that it will abide. Of course, some revisions, changes, and continually enlargements, will always be necessary; but it scarcely seems possible that another such revolutionary revision of Physics-Teaching can be called for in the next half-century, if ever again.

### 3. What Is the Proper Grade of Work.

It is assumed that students come to the work of this Department prepared in the Secondary School Physics; and we endeavor, even, not to accept the poorer grades of that work without some supplementing.

But necessarily, the School Physics embraces but a limited treatment of each of the main divisions of Physics. Any one of these divisions, without going to a higher plane of principles or of treatment, affords matter enough to occupy all the time that we can give it in the College work.

Shall we attempt to give this fuller, more complete, body of information on the given subject? Or shall we give an introduction to a more advanced, i. e., more comprehensive and powerful, method of treatment of the subject, though fewer points of information be thus acquired?

Considering that the student is more mature, has also two years more of mental discipline, and about two years of mathematical attainment, it seems to me an injury and an injustice—especially hard on the best students—to consume College time in acquiring a large store of details of information which any High School boy might acquire—however valuable the information.

Such text-books, or such a treatment of any subject, should be given as will use the greater mental maturity and discipline and mathematical tools, of the good student to the full extent.

Of course, those whose misfortune or whose fault it may be not to have the proper mental discipline or mathematical training will suffer some inconvenience, or failure. But they can acquire the discipline and the mathematics, and try again. On the other hand, if the lower range of work is used, the best men have no opportunity to do the work of most benefit, for taking the lower work a second time would only double the injury.

I have been making trial of what grade of work our students can carry. Last year, this was interfered with by a change in the order of the study of Elementary Mechanics, and this year there is interference (apparently necessary) by the changes required to enter upon the new schedules next year. The former of these interferences has been removed; the latter exists for this year only. But there is one other serious hindrance, which I hope can also be removed in the near future; namely, the lack of one session's work in one mathematical subject. The greater maturity, the two years additional discipline beyond the High School, and two years of mathematical study, can never be used to full advantage until the latter is made to include one session of work in Calculus. Roughly, there are two grades of text-books in Physics, or more fundamentally, of methods of treating the subject; one involves only the Algebra and Geometry of the High School or so much of Trigonometry as a High School boy might learn in a few hours; the other involves Analytic Geometry and the first elements of Calculus. It is wrong to require students who have the aditional age, the discipline of study, and the additional mathematics (except a few weeks' work in Calculus) to study Physics treated by the lower method; for the study treated by the higher method they are at some disadvantage. This would be removed by requiring Solid Geometry for entrance, thus bringing Calculus one session earlier. It is very desirable that this be done as early as possible.

## 4. Physics in Education.

To estimate and assign the place of Physics in Education, there must be a true conception of Physics and of Education.

The nature, extent and relations of Physics are but imperfectly understood by very many. Many think Physics a single, distinct and limited science—like Botany, Zoology, Calculus, or Psychology. If we group together Botany, Zoology, Anatomy, Physiology, Histology, and Embryology, and call all this Biology, we shall only have a science of such rank and extent as to be co-ordinate with Physics. Or if we group together Psychology, Ethics, Logic, Aesthetics, Politics, Philosophy, and call all this Metaphysics, we shall only have another science of co-ordinate rank with Physics. Or, once more, if we group together Arithmetic, Algebra, Geometry, Trigonometry, and all the forms of General Geometry and Calculus, and designate all this Mathematics, we shall only have another science co-ordinate in rank with Physics.

The principle and the truth of these statements are shown more clearly in the following chart:

| Entities. | Sciences. | |
|---|---|---|
| | Genera. | Species. |
| Mind, | Metaphysics, | Psychology.<br>Logic.<br>Aesthetics.<br>Ethics.<br>Politics.<br>Philology.<br>Philosophy. |
| Life, | Biology, | Botany.<br>Zoology.<br>Histology.<br>Anatomy.<br>Physiology.<br>Embryology. |
| Energy and Matter, | Physics, | Dynamics.<br>Chemistry.<br>Mineralogy.<br>Astronomy.<br>Wave Motion.<br>Heat.<br>Electricity. |
| Space and Time, | Mathematics, | Arithmetic.<br>Algebra.<br>Geometry.<br>Trigonometry.<br>General Geometry.<br>Calculus. |

The great entities (below the Divine Being) known to us are Mind, Life, Energy (and Matter), and Space and Time. The part of certain and systematized human knowledge that is concerned with each of these great entities constitutes a genus of science, consisting of a number of particular and limited sciences as species. Physics is a genus; and its species, as Dynamics, Heat, Electricity, etc., rank in order with Botany, Zoology, etc.; with Geometry, Calculus, etc.; with Psychology, Logic, etc. Indeed, three of the special sciences of the genus Physics are so extensive and important that they are generally thought of as independent departments of human knowledge—Chemistry, Mineralogy, and Astronomy. Yet these are logically and truly only special sciences belonging to the generic science Physics. Chemistry considers energy acting on molecules of matter to change their constitution. Mineralogy considers energy giving constitution and definite forms to masses. And Astronomy considers energy acting on very great masses of matter.

Let us now define Physics; and please remember the definition: Physics is the science of energy (and matter). This definition marks the true comprehension of Physics.

Energy has many forms or modes of acting, known as forces. It is, in some form, the cause of all the phenomena known to us, save those which are purely vital (if there be such) or purely mental. So, all phenomena, save those of life and of mind, are physical phenomena; and, indeed, almost (if not quite) all the phenomena of life arise out of, are accompanied by, and result in some action of energy, or physical forces. Even mental action always calls into activity physical forces.

The knowledge of physics is fundamental, and is therefore indispensable in all great departments of human knowledge—possibly excepting pure Mathematics. The laws of Physics control, alone or associated with those of Life and of Mind, all things of which we have sensible knowledge. All geological actions from the shooting of a crystal to the shaping of a continent and the uplifting of mountains are the products of physical forces acting under physical laws. The flora and fauna of the world have been changed time and again; and these changes were wrought by the operation of physical forces, and can be interpreted and understood only by physical principles. The laws of Physics govern the tides, the winds, the meteors, space-wandering comets, and the eternal stars in their ordered courses. Their bands are thrown about far Orion and hold with sweet influence the clustered Pleiades. Circulation, absorption, respiration, locomotion, flight, in the vegetable or the animal world, are purely physical actions. And every act of emotion, volition, or thought, in brute or man, is associated with molecular movements and changes, with heat and electrical action, all in accordance with physical laws, and capable of being studied by the methods of Physics.

To repeat the thought, and sum up thus far: Physics is not a special science with a limited field. It is generic, and its domain extends wherever Energy, in any form, is acting upon or with matter.

Let us consider briefly the importance of Physics in the arts and professions, and in the conduct of life.

If we turn to the ocean with those who "go down to the sea in ships," the knowledge of the motion and force of currents and waves, of the buoyancy and equilibrium of ships, of the movements of vessels through water, of the effect of the winds on the sails or the steam on the piston, of approaching tempests and the laws of storms, of magnetic action, of methods of taking latitude and longitude, and the whole art of naval construction, seamanship, and navigation, are but applications of Physics.

When we approach the land, we behold the triumphs of engineering skill—the light house on storm swept reefs defying the anger of ocean and air as they hurl their might in hurricanes on the rock-ribbed shores; the harbors and docks which shelter the navies of the world; the magnificent bridges under whose arches flow rivers that drain continents and carry ocean steamers; the tunnels that pierce the rocky cores of mountain ranges; the mines that furnish the metallic basis of civilization; the railroads, telegraphs and machinery that are the material implements of science and of civilization. It is true that "the whole employment of the engineer is a continual application of almost every branch of physical science."

In war, the military engineer is continually using the tremendous energies of physical forces. Upon his knowledge of their laws and skill in their use, far more than on the brute weight of legions, depends victory or defeat.

The architect must know the physical properties of matter and the laws of action of forces, or he can execute no great works. Walls and arches and domes and spires, to have the strength which gives security and the elegance which gives delight, depend on the nicest adjustments of strength of materials and equilibrium of forces.

If we turn to what are called professions, it would seem needless to speak of the importance of Physics to the physician. All the better medical colleges now require a considerable knowledge of this science for admission or provide for its study in their courses. He must be an empiric and a blunderer, indeed, who practices medicine without a thorough knowledge of physical laws. The animal body is a marvel of physics. All its structures and movements embody and employ mechanical and dynamical principles. The heart and blood vessels are a hydraulic mechanism in ceaseless action. The principles of pneumatics govern respiration. The larynx and the ear are acoustic, and the eye an optic apparatus of the most delicate structure and wonderful powers. The vigor of the whole organization and the maintenance of life are dependent on heat, light, electricity, atmospheric conditions, properties of food, that can be used with therapeutic skill only by those versed in Physics.

The lawyer who is acquainted with the great laws which govern the material world, possesses immense advantages over the one who is ignorant of these in all suits about inventions, machines, and manufactures; about accidents in navigation, or on railways, or by machinery; and about disputes growing out of the action of winds, or floods, or electric storms, or other physical agencies.

If the clergyman is ignorant of the principles of the material world, its constitution and activities, he is incapable of using a large part of the evidences of the power and intelligence of a personal God which are the most universally intelligible and convincing to all men, and which alone can be used to persuade those who are doubtful of the authenticity of revelation. He is poorly equipped, whatever his other attainments, to meet the intelligent skepticism of to-day who has not a fair knowledge of Biology and Physics.

Having thus briefly reviewed the nature of Physics, its rank and relations among the great divisions of human knowledge, and its fundamental and universal importance in the affairs of life, Education should now be considered, its nature, its purposes, the means and methods employed. A discussion of the nature of education would lead so far into the vast field of psychology that it is precluded by the limits and scope of this paper. Indeed, the purposes, means and methods of education are much more important in this connection than the ultimate nature of mind or the recondite laws of its growth and activities. Largely and briefly, the purposes of education may be divided under two headings. The first, the larger and truer purposes of education is to aid the growth and direct and train the activity of mental faculty for its own perfecting. The second purpose of education is the acquisition of knowledge. To these, we must add a third purpose, which has become very prominent and to which great importance is attached in recent times, skill in doing useful things. The emphasis here is on useful: for doing certain things, as music, painting, etc., has always from the most ancient times been held to be educational, that is in the stricter meaning of enriching personality. But in this age, specific preparation for acquiring skill in doing things that are useful, in the sense of earning money by the production of the material necessities and commodities of life, is included in education.

Now it is not possible to accomplish any one of these purposes exclusively. He who is gaining skill in useful craft is also acquiring of necessity some knowledge, and by both these is enlarging his own being in some degree. He who is ackuiring knowledge is of necessity improving mental faculty.

But according to the predominance given to one or another of these purposes will one or other means and methods be selected; or, any given means or method will be given very different value.

What means are available for the highest purpose of education—the growth of mind, the training of faculty, the production of the highest perfection attainable? "Is there a Hierarchy of Studies?"

Yes, most emphatically, there is. Reason affirms it. Experience confirms it. It is testified by the ablest and most experienced educators. Four years, or any other period, of equally strenuous effort, is not of the same value whatever may be the subjects studied. Mind, and Life, and the physical Universe of Energy and Matter, and Space and Time, all are products from the same origin, interpenetrated with the same great principles, and in closets interrelation. Reasonably, the balanced, fullest growth of mind, the most vigorous and perfect action of its every faculty, to the end of its highest being, are to be attained only by a due relation to all its environing and conditioning correlatives. A good education, in the true and full meaning, must include just proportions of the four great generic divisions (See Chart), Mathematics, Physics, Biology, Metaphysics.

Let this be emphasized by negative repetition: There cannot be a good education that does not contain a due proportion of each of these. There may be great acquisitions of knowledge; the second purpose of education, a necessary incident to it, and often confounded with it. But there can be no good education in which any of these generic divisions has not just part. A good education cannot be obtained without these four elements.

Experience confirms this. Look, not at the tedious multiplicity of detail, but with general view along the history of education. If in any place or age there has been an institution or system of education that included but one of these four grand divisions, it has not survived, proof it was not the "fittest." The surviving educational system of the foremost nations dates back to the founding of the European Universities. Its centuries of survival certainly prove a great degree of "fitness." It has developed, too, another proof. Let us ask wherein it is now better that it was some centuries, or even one century, ago. Then, two of the four fundamental parts had an undue proportion, Mathematics and Metaphysics. The great improvement of Education in modern times in the bringing up to their just proportions in the system of Physics and Biology. Indeed, during part of the last half century, there was a strong movement (not yet fully spent) to give Physics and Biology undue share, especially by reduction of Metaphysics.

Looking especially at Education in American Colleges, with a history and experience based on the European Universities and extending over more than two centuries of independent development—President Gilman of Johns Hopkins gives this terse summing:

"The experience of American Colleges has shown that the most available as well as most efficacious studies in a liberal course of training are (a) Mathematics, leading to (b) Physics and Natural Science; and (c) Language, leading to (d) Political and Moral Science." —North American Review 6-83, P. 534.

Mathematics, Physics, Natural Science (i. e. Biology), and subjects in Metaphysics. President Gilman's statement of what experience has confirmed as fittest to survive in American Colleges is in accord with our four fundamentals—its cause and explanation.

Physics in Education: Clearly, Physics is one of four great coordinate and fundamental parts which together embrace all science, or knowledge: without just attention to which there can be no sound education.

When it was said, a little above, that the standard system of education which has survived through centuries of trial has been made better in this last century, it was not meant merely that a new kind of information was added or greatly increased, that more knowledge of physical (and biological) laws and phenomena was included, and that the educated man of the present is less ignorant concerning the material world than formely.

The improvement is this, that when given due rank, and therefore allotted proper time and effort, the study of Physics exercises the faculties in a discipline very different from that of mathematical work, or of the linguistic and philosophic work of the Metaphysical division. The mind itself thus exercised is different from what it would be without this kind of discipline. The personality is different, not simply because of a different stock of knowledge on hand, but because, fundamentally, of a different growth of mind in response to this special line of activity sufficiently maintained.

This is equally true of Biology, or of Mathematics, or of Metaphysics—each exercises the faculties in a discipline different from that of the others. For this reason, all are necessary to a liberal education.

It is an important question what amount of each of these the curriculum should contain.

It is manifest at once that no student can become proficient in all the specific sciences under the four generic subjects. Shall a superficial knowledge of all these be demanded, or more thorough work in a few species under each genus? The peculiar discipline which the proper study of physical science gives does not depend on cramming an encyclopaedic quantity of scientific facts. "A liberal education requires an acquaintance with scientific methods, with the modes of inquiry, of observation, of comparison, of eliminating error and of ascertaining truth, which are employed by modern investigators:" and above all, the habit of mind acquired by such work. Such an acquaintance, and such mental habit, are best attained by, first, the acquisition of knowledge and the training derived from a study of the elements of several of the species; and, second, the prolonged and thorough study of some one, as Dynamics, or Chemistry, or Heat, or Electricity.

This work in Physics should be done partly in the Secondary School, partly in the College, and completed, if may be, in the University.

In the elementary instruction in Physics there should be as full experimental illustration, of a suitable character, as possible, accompanying thorough study and drill in a good elementary text book; and after this (or partly coincident) some experimental work, at least partly quantitative, by the student, in the laboratory. So far, much importance should attach to the acquisition of knowledge and ideas, physical facts, qualities, phenomena, and a correct terminology. Howbeit, the training and discipline of method, and mental habit are beginning. This is the proper work of the High School and the Academy.

This should be followed by the study of a text-book, or books, of a more mathematical rather than descriptive character, requiring a relatively less amount of illustrative experiment: though of the very great value of such lecture experiments as are proper for this work there can be no question. But a large part of the experiments most valuable in this grade of the study are of a kind that cannot be exhibited profitably to a class, but rather require individual performance, with time and opportunity to observe the conditions and phenomena to make suitable adjustments and careful readings of measuring instruments. For this, the first college grade of work in Physics study, the text-book and recitation, with due illustrative experiments, can never be profitably abandoned for the lecture method; in which the student gets but little, in accurate and useful form, unless he spends undue labor and time in note writing. This grade of the work should add considerably to the store of knowledge, of facts of higher order, or in larger relations. But relatively much greater importance should attach to the distinctive discipline and the habit of mind accruing from scientific methods.

The highest grade of Physics study is almost purely mathematical and philosophical; the mathematical and logical discussion of the data obtained by observation and experiment; the obtaining from these of laws, and from these again the forming of a theory, a logical system of principles. The full development of this grade of work in Physics combined with original research is university work: nevertheless, to a degree and in a manner possessing high educational value, it must have place in every college as one of the four indispensable elements in a balanced liberal education.

On this subject of the order and quality of the work and the best methods in Physics in Education, the views of Dr. Mendenhall are given in the following (much condensed) quotation. Dr. Mendenhall, now President of Worcester Polytechnic Institute, is a physicist of ability and one of the foremost living teachers of Physics. He says, in substance, "Teaching should be accompanied—not taking the place of nor surrendering itself to it—by experimental work: quantitative, by the student, in the laboratory and illustrative, on the table of the instructor. It is not a matter of great importance on what particular department of Physics a student shall spend his time and strength. The underlying principles of the method are common to all: skill in one begets facility in the others; and the discipline of any one is the same as of any other. To sum up, the Course of study in Physics for the undergraduate collegian should include a sufficient training in Mathematics to meet the more common physical problems: a thorough and exacting course of text-book work, applying the mathematical ability acquired, and illustrated by the experiments necessary for a complete understanding of the text: and a course in the laboratory in which more attention is given to the quality than to the quantity of the work done; during which every problem is discussed, as far as possible, both mathematically and experimentally, and especial attention is given to the discussion of the results of experiment and to the elementary portion of the theory of errors."

A large and very important part of the present system of education is Technological Education, or as commonly called, Technical Education. This is, in so large part, in the State Colleges founded on the Land Grant Act of 1862, and these Colleges are so nearly entirely occupied with this kind of work that they may be taken as its exponent. There was at first, for some years, danger that these would be compelled, through popular misapprehension, to be technical, rather than technological, schools, that is, mere trades schools training artisans. Happily, we may believe this danger has passed.

At present, the following is the status of the typical State-National College: It is trying to put into four years (following the Secondary School), an education, in the old, true, high meaning of that term, and, a preparation for technical work of professional rank. The new wine would scarcely go in the old bottle; so the bottle has been, partly at least, made over anew; and the question is whether the old wine with its excellence is in the half-new skin.

I have watched with interest, and sympathetically, this attempt. The effort has been worthy of high commendation, and has appeared almost successful in some instances. But are there not indications that an education and a technological preparation cannot both be satisfactorily compassed in four years, starting from the Secondary School?

Coming to the more immediate subject, of course the very great importance of Physics in Technological Education is readily granted; not only its educational value, but its very great practical value. And yet, there are strong influences operating against good work in Physics in the Technological Education of the present time. First, a large number (if not a large majority) of technical students are careless or even impatient of education for its own sake and are eager only for immediate preparation for profitable work. They ask about everything, "Can I use it, directly, in what I am going to do?" The continued, systematic, logical study that is discipline and education is irksome. They wish simply to acquire the points, the facts, that can be immediately applied. He who tries to hold a class, largely of those who have this mental "habit," or attitude, to a course of work for its pure science and its educational values, will feel that "Virtue has gone out of him."

But, secondly, are there not occupants of the chairs of Physical Science and of Technology in some of our institutions who encourage or confirm this idea that the prime object of the student should be to acquire those things that will be of most frequent and important use in a certain technical course?

Thirdly, the attempt (noticed above) to put an education and a professional training in four years, almost necessitates this selection of important practical points in science work rather than a logical and disciplinary order of study.

Fourthly, the selection of a specific course, Mechanical or Civil Engineering, or Chemistry, or Agriculture, etc., at the very beginning of the four years, makes doubly active the pernicious mental habit of the technical student to view everything with reference to what immediate use he can see that he can make of it in the work he has chosen.

Fifthy, the student is provided in some at least of his technical work with text-books that are favorable to this sketchy and imperfect work in science study: text-books that are conglomerates, part science sketches, part technology: just the points of the science that must unavoidably be at command. This kind of textbook may be necessary: but the necessity should be abated, by provision for proper training in the science, training of both educational and scientific value: and then the work on a technical subject should no more provide the (unprepared) student with the scientific points than it should contain a collection of the mathematics to be used in it.

These are some of the influences adverse to the best interests of Physics in Technological Education. They can all be overcome, though some of them may continue a long time.

Perhaps the most fundamental and efficient practicable remedy is that embodied in the following diagram. There are indications that in a decade or two such changes will be accomplished.

|  | Secondary Schools. | Colleges. |  |  | Technical Schools. |
|---|---|---|---|---|---|
|  |  | Freshman. | Junior. | Senior. |  |
| Math., | Mathematics, | Math., | Electives. |  |  |
| Physics, | Science, | Phy | sics. |  |  |
| Biology, | Elements, | Biol | ogy. |  |  |
| Metaph., | Language, | Lang., | Metaphysics. |  |  |

Probably before a score of years the technical institution that does not base its course on about such requirements will not be in the first rank. Two or three approach this pretty closely now.

When an academic college education is required for entrance to technical schools, and is made separate from them, there will be much better work done, and larger benefit to the student, in Physics and in all education. The student will have truer aims and ideas, and be free from the continual thought "This is of no use in my work." When young men begin to direct preparation in their chosen life-work, they will not do much with what does not appear to them to have immediate use therein. Try to keep up mathematical study in a law school, for the benefit of the rigorous discipline of the logical powers! Try to keep medical students at work in civics and philosophy, for their value as a training in discursive thought and their value in mental therapy!

Put technical training where it belongs, in rank with the schools of law, of medicine, of divinity, in this respect at least, that it is a direct preparation in the chosen work of life and must have a secure and broad foundation in a truly liberal education: and when entered upon, let it be, as in professional schools, pursued with undivided purpose.

If it should seem to any that I have not kept very strictly and exclusively to the subject of Physics in Education, but have made a somewhat general discussion, my justification is that Education does not consist of separate and unconnected parts: its parts have organic connection, and no one can be isolated and discussed alone.

Respectfully submitted,
I. THORNTON OSMOND,
Professor of Physics.

State College, Pennsylvania, May 24, 1900.

# XVII.—PSYCHOLOGY AND ETHICS.

To the President:

Sir:—It is a pleasant duty to report herewith the work of the Department of Psychology and Ethics for the past year, and to record the hopes and aims of the future. It is but due to affirm that the results, so far as they are apparent, show improvement over previous years. The gaps in one's historical knowledge of growing subjects diminish somewhat with each succeeding year; while the vital hold upon the student increases with the greater spontaneity and freedom rendered possible. The same facts and principles need different statement and emphasis in order that different classes may appreciate them. No two individuals, it seems to me, approach a subject in quite the same way, so that it is one of the perplexities and at the same time one of the joys of the teacher constantly to remould the material in order to insure to the student the largest opportunity for personal growth and expression.

The remoulding of the general courses has made it possible to secure a logical arrangement of the subjects of the department. Beginning with the second session of the Sophomore year, the work is now continuous and consecutive throughout the course. I have every reason to expect better work under the new schedules. At the same time, the urgency of extending these subjects to all the courses grows upon me. I beg to submit the following as expressing the wishes of the department.

Some general considerations are first in place. The question of psychological subjects in the curriculum is not the question of the old education against the new. It is entirely independent of either classical or scientific movements. The general recognition of these subjects is based upon intrinsic considerations, and not upon a theory of education on whose carrying power alone they rely. Psychology is the study of mental life, its activities and laws. It is the basis of all the sciences that deal with man and his relations to his fellows. As such it ought to be carefully fostered and pursued. Again, while keenly appreciating the value and power of the sciences of external nature, surely the science of the internal nature (which at every step conditions the study of external nature), should have its place as one of the most essential phases in education. Moreover, from the point of view of utility, I think the case of psychological study a good one; since the knowledge of men, the springs of action, the processes and laws of thinking, the emotional bias and anti-bias are real sources of success and failure in business, social, and moral life. I have affirmed in other connections (and it is not mere poetical metaphor either), that one cannot fully understand the growth of plants, the processes of crystallization—even the running of a locomotive, without a knowledge of psychology. However that may be, the fact cannot be too frequently emphasized that we really do more for our special interests by doing less for them, and consequently doing more for other interests closely related thereto.

In the Report for 1896, I had the honor to suggest as worthy of serious consideration the advisability of incorporating the subjects of psychology and ethics at least into all the courses. In the Report for 1897, that suggestion was amplified in the light of the principles of education as I conceive them. Subsequent events have but deepened these convictions Confirmation, too, is not far to seek. The profounder applications of psychology to life, to education, to social study and theory which mark the present, together with the historical justification and "pedagogic form" which the field of psychology presents constitute an irresistible appeal for recognition in any course of collegiate instruction.

In this connection, permit to quote from a report of a Committee of Five on the Curriculum of Land-Grant Colleges (Report of the Commissioner of Education, 1896-1897), which reads in part as follows:

"Section 5. The educational conditions prevailing in the United States make it impossible to require of students in schools of applied science or technology that their liberal training should be acquired in preparatory schools. These institutions, therefore, cannot exclusively confine their attention to technical subjects. They must include in their courses for graduation certain elements of a liberal (or general) education.

Section 6. These considerations, thus briefly outlined, make it desirable that all colleges in membership with this association should unite in requiring for the bachelor's degree or degrees at least the following general studies:

(To the subjects enumerated, I add from section 7, the hours approximately assigned upon the basis of 15 hours per week of recitation and 10 of practicum, for 36 weeks and for a full course of four year.)

| | |
|---|---|
| Algebra, Geometry and Trigonometry, ............... | 155 hours. |
| Physics and Chemistry (including 150 hours laboratory), | 300 hours. |
| English, .............................................. | 200 hours. |
| Modern languages, ............................. | 340 hours. |

| | |
|---|---|
| Psychology, and Ethics or Logic, .................... | 100 hours. |
| Political Economy and Constitutional Law, ........... | 110 hours. |
| General History, .................................. | 80 hours. |

"Thus about two-fifths of the work required for the bachelor's degree is comprised in the above named general branches."

It should be distinctly remembered that the subjects of psychology and ethics are such that they are not and cannot be pursued by preparatory students. They demand for their appreciation considerable maturity of mind. Their proper place is thus in the last years of a college training. No increase in entrance requirements eliminates them from the curriculum. Their omission on any grounds cannot but be viewed as a serious injustice to both students and to the subjects themselves.

The vital element of the Report, however, lies not in the enumeration of subjects and hours. Of far greater import is the affirmation of the principle that the pall cannot be drawn over educational requirements. There is implicit recognition also that one of the critical problems of our national educational system is being worked out in these institutions, viz: How, on the one hand, shall the technical work be raised to high collegiate grade; and on the other, (owing to existing conditions), how shall the strictly professional or university training in these lines be brought into conformity with the admitted essentials of collegiate education. Educational requirements must always precede technical demands. The trained mind and heart are fundamental to true success in any field, and in such training, the study of the mental sciences, (logic, phychology and ethics) has every where been recognized as integral and essential.

I have no intention at present to enlarge upon the reasons which underlie this view and its practice, nor am I proceeding for a moment on the assumption that such is necessary. My only wish is to record my conviction that every course leading to a bachelor's degree should include at least one year's work in psychology and ethics. In affirming this, I am not unmindful of the pressure of other subjects and of the increasing demands in technical lines. But such pressure and demands only emphasize the more the constancy of the basal elements. They render more imperative the essentials of education as over against the necessities of professional training. They do not in any sense make the former superfluous or merely desirable. It is to be hoped that the increase in entrance requirements and a readjustment of the relative emphasis upon subjects will speedily make it possible to incorporate these branches into all the courses. The careful report of the Committee of Five, as above noted, and that also of the Society for the Promotion of

Engineering Education (to mention but two cases), maintain the advisability of increase in entrance requirements. The former report advocates no less unqualifiedly the assignment of One Hundred Hours to Psychology, logic or ethics in all courses leading to a bachelor's degree. That a readjustment of relative emphasis upon subjects in the several courses is feasible needs no comment. The Junior year, containing in the main no general subjects, affords the logical position for the insertion of Psychology, four hours per week during the first session, and an option between Logic and Ethics, three hours per week during the second session.

As a matter of fact, some of the technical courses do provide for instruction in psychological branches. The uniformity of such provision which I would respectfully urge springs wholly from a view of educational principles and not from any external desire of department representation. I have found those pursuing technical work to be keen and earnest students of these branches; and it is the right and the duty of every candidate for a degree to acquire a knowledge of the fundamentals of his own inner life, or its relation to things (the basis of the sciences), and its relation to other minds (the basis of conduct, social order and of the state).

Our needs remain substantially as in the last two Reports. The laboratory equipment should be extended so as to embrace projected lines of work, which lack of funds have made it impossible to carry out. The necessity of a considerable increase in books is keenly felt. The binding of Journals, so as to make them more accessible to students, is also essential to our work. These and other necessities of the department will be detailed in a separate and later report.

Respectfully submitted,
ERWIN W. RUNKLE,
Professor of Psychology and Ethics.

State College, Pennsylvania, May 24, 1900.

## XVIII.—SUB-FRESHMAN CLASS.

To the President:

Sir:—The annual report of the Sub-freshman, or preparatory department is respectfully submitted.

In this, my first year in charge of the class, its importance to the college proper has very naturally been impressed upon me as never before. Even at the risk of going over ground very familiar to you, permit me to review briefly some of the advantages of maintaining such a class. In the first place, it performs what may be called a negative service by saving students to the college in that it affords an opportunity for those freshmen poorly prepared in certain subjects to bring up such deficiencies while continuing the regular work of their class. During the past year there have been twelve such students attending one or more courses of recitations in this department. In the second place, it confers a positive benefit upon the college by presenting to each entering class a considerable number of students. Fully 90 per cent. of the students completing the Sub-freshman year enter the college as freshmen, and in some years the percentage has been even larger. Further, my experience in teaching freshman mathematics has convinced me that the graduates of this department are, as a rule, better prepared than students coming from other schools, which will be indorsed, I am sure, by other members of the college faculty. In this connection the following table, showing the number of the graduates of the college since 1895 who completed the sub-freshman year, may be of interest:

| Year. | Number in class. | Number from Sub-F. class. | Per cent. |
|---|---|---|---|
| 1895, | 35 | 7 | 20 |
| 1896, | 30 | 17 | 56+ |
| 1897, | 36 | 9 | 25 |
| 1898, | 43 | 16 | 37+ |
| 1899, | 44 | 10 | 22+ |
| 1900, | 40 | 14 | 35 |

Yearly average from Preparatory Department, 32 per cent.

It was owing to these considerations that a pamphlet, detailing the advantages of the class and giving its courses of study, has been issued, with your consent and advice, of which many copies have already been distributed and others are now being enclosed with the college catalogues sent through the mails.

In this department at this time there are thirty-four taking the regular course, all but two being in full standing and these last are deficient in but one subject each, which they expect to bring up by the beginning of the next college year. In addition to this number there are two students who upon trial proved too poorly prepared to carry the work of the class, but who are endeavoring, under the supervision of the Department, to fit themselves for entrance with next year's freshman class. I am glad to report that this year's Sub-freshman class has shown such attention to business and given such evidences of ability as to assure a well prepared and thoroughly satisfactory nucleus for the class of 1904.

The work of the past year has followed closely the course of study outlined in the college catalogue, and the members of the class have had careful training in all prescribed subjects. A student deficient in any subject has been required in every case to tutor a prescribed number of hours under an approved instructor, a plan which has secured most satisfactory results. A marked improvement in the presentation of the course in elementary physics demands particular notice. During the past year the recitations in that subject have been held in the physical laboratory, and through the kind co-operation of the Head of the Department of Physics in furnishing apparatus, and the painstaking efforts of Mr. Riggs, the class has had the privilege of seeing many suggestive experiments performed. That this has been of great benefit is shown by the interest excited and the good results achieved in point of scholarship. Of the work of the year as a whole it may be said that while mistakes have doubtless been made, the effort of the entire department toward demanding thoughtful and thorough work on the part of the student has been, in the main, successful.

For the following year, I would respectfully recommend the following:

1. That more time be given to the subject of English as recommended by my predecessor, Dr. Benedict. Mr. Espenshade deserves great credit for the amount of work he demands and secures in the one term's study of English classics, but the time at his disposal is inadequate for the training needed. College students are noticeably deficient in English, and for this reason it would seem advisable to diminish the number of hours required for drawing in the first session from five to four in order to add to the prescribed course of study a two-hour practicum weekly in English.

2. That the rhetorical work of the class be under the direct supervision of the English Department. This, it seems to me, is the only way in which effective work can be attained.

3. That an appropriation of $250 be devoted to the purchase of apparatus for teaching elementary physics. The scarcity of such apparatus has made it necessary to omit many experiments altogether and has made it impossible to allow the students to perform for themselves any experiments whatever, to their manifest disadvantage.

4. That rules for the government of the Sub-freshman class adapted from the present college rules be put into the hands of the members of the class.

In conclusion, allow me to thank you, Mr. President, for your most helpful suggestions and advice, and to acknowledge to Miss Redifer and Dr. Taliaferro, in addition to those previously mentioned, my appreciation of their excellent work with the Sub-freshman Class.

Very respectfully,
JOHN H. LEETE,
In charge of Sub-Freshman Class.

State College, Pa., May 24, 1900.

# XIX.—REPORT OF THE TREASURER.

From July 1, 1899, to June 30, 1900.

State College, Pa., Jan. 22, 1901.

To the Board of Trustees of The Pennsylvania State College:

Gentlemen:—The following report of the Treasurer of The Pennsylvania State College, from July 1, 1899, to June 30, 1900, is respectfully submitted. The accounts are arranged under the following titles, corresponding to the ledger headings in the college books of account:

1. The College general account.
2. The United States account, act of 1890.
3. Eastern and Western Experimental Farm interest account.
4. State appropriation act of 1893.
5. State appropriation act of 1895.
6. State appropriation act of 1897.
7. State appropriation act of 1899.
8. Experiment Station, general account.
9. Experiment Station, United States account, act of 1887.

## The College General Account.

| | Dr. | Cr. |
|---|---|---|
| **Dr.** | | |
| To amount received from land scrip fund, | $30,000 00 | |
| To amount received from proceeds of notes discounted, | 65,268 88 | |
| To amount received from students and all other sources, | 37,933 29 | |
| **Cr.** | | |
| By balance due Treasurer June 30, 1899, | | $305 37 |
| By amount paid College expenses, | | 131,648 49 |
| By balance in hands of Treasurer June 30, 1900, | | 1,248 31 |
| | $133,202 17 | $133,202 17 |

## United States Account. Act of 1890.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $12 92 | |
| To amount received from the Treasurer of the United States, | 25,000 00 | |
| **Cr.** | | |
| By cash paid College expenses, | | $24,397 38 |
| By balance in hands of Treasurer June 30, 1900, | | 615 54 |
| | $25,012 92 | $25,012 92 |

## Eastern and Western Experimental Farm Interest Account.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $1,840 00 | |
| To amount received from State Treasurer, | 1,020 00 | |
| **Cr.** | | |
| By cash paid College expenses, | | $2,815 44 |
| By balance in hands of Treasurer June 30, 1900, | | 44 56 |
| | $2,860 00 | $2,860 00 |

## State Appropriation. Act of 1893.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $62 88 | |
| **Cr.** | | |
| By cash paid College expenses, | | $58 25 |
| By balance in hands of Treasurer June 30, 1900, | | 4 63 |
| | $62 88 | $62 88 |

### State Appropriation, Act of 1895.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $183 86 | |
| **Cr.** | | |
| By cash paid College expenses, | | $72 10 |
| By balance in hands of Treasurer June 30, 1900, | | 111 76 |
| | $183 86 | $183 86 |

### State Appropriation. Act of 1897.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $4,211 28 | |
| To sundries, campus account, and refunding of store account, | 43 75 | |
| **Cr.** | | |
| By cash paid College expenses, | | $4,176 82 |
| By balance in hands of Treasurer June 30, 1900, | | 78 21 |
| | $4,255 03 | $4,255 03 |

### State Appropriation. Act of 1899.

| | | |
|---|---|---|
| **Dr.** | | |
| To amount received from State Treasurer, | $30,512 43 | |
| To proceeds of note discounted, | 2,000 00 | |
| **Cr.** | | |
| By cash paid College expenses, | | $30,747 23 |
| By balance in hands of Treasurer June 30, 1900, | | 1,765 20 |
| | $32,512 43 | $32,512 43 |

### Experiment Station General Account.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $83 73 | |
| To amount received from analyses of fertilizers, | 8,217 00 | |
| To amount received from notes discounted, | 4,950 00 | |
| To amount received from all other sources, | 3,447 13 | |
| **Cr.** | | |
| By cash Experiment Station bills paid,. | | $17,312 32 |
| To amount due the Treasurer June 30, 1900, | 614 46 | |
| | $17,312 32 | $17,312 32 |

### Experiment Station, United States Account.

| | | |
|---|---|---|
| **Dr.** | | |
| To balance in hands of Treasurer July 1, 1899, | $335 26 | |
| To amount received from Treasurer of the United States, | 15,000 00 | |
| **Cr.** | | |
| By cash paid Experiment Station bills, . | | $15,243 58 |
| By balance in hands of Treasurer June 30, 1900, | | 91 68 |
| | $15,335 26 | $15,335 26 |

## SUMMARY.

### College Account.

| | | |
|---|---|---|
| **Dr.** | | |
| Balance on hand July 1, 1899, | $6,005 57 | |
| Total received to June 30, 1900, | 191,778 35 | |

Cr.

| | | |
|---|---|---|
| By amount expended to June 30, 1900, .. | | $193,915 71 |
| By balance on hand June 30, 1900, ...... | | 3,868 21 |
| | $197,783 92 | $197,783 92 |

### Experiment Station.

Dr.

| | | |
|---|---|---|
| Balance on hand July 1, 1899, .......... | $418 99 | |
| Total amount received to June 30, 1900,. | 31,614 13 | |

Cr.

| | | |
|---|---|---|
| By amount expended to June 30, 1900,. | | $32,555 90 |
| By balance due the Treasurer June 30, 1900, ............................ | | 522 78 |
| | $32,033 12 | $32,033 12 |

### TOTAL.

| | | |
|---|---|---|
| Total receipts including balance on hand July 1, 1899, ....................... | $229,817 04 | |
| Total expenditures to June 30, 1900,.... | | $226,471 61 |
| Balance in hands of Treasurer June 30, 1900, ............................ | | 3,345 43 |
| | $229,817 04 | $229,817 04 |

Respectfully submitted,
JOHN HAMILTON,
Treasurer.

# CLAYS AND CLAY INDUSTRIES

OF

# PENNSYLVANIA.

## III. CLAYS OF THE GREAT VALLEY AND SOUTH MOUNTAIN AREAS.

DESCRIPTION OF THE CLAYS AND CLAY-WORKING INDUSTRIES IN THE GREAT VALLEY AND SOUTH MOUNTAIN AREAS IN SOUTHEASTERN PENNSYLVANIA, COVERING PORTIONS OF FRANKLIN, CUMBERLAND, YORK, LANCASTER, DAUPHIN, LEBANON, BERKS, LEHIGH AND NORTHAMPTON COUNTIES.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

THOMAS C. HOPKINS.

APPENDIX TO THE ANNUAL REPORT OF THE PENNSYLVANIA STATE COLLEGE, FOR 1899-1900.

8—21—1900

University of Chicago,
April 10, 1900.

Sir:—I have the honor to submit herein my report on the clays and clay industries of the Great Valley and South Mountain areas of southeastern Pennsylvania, prepared according to your instructions. The field work was done during the summer of 1899 and the office work during the past winter. This report is the third in the series on the clays of Pennsylvania and the fourth on the economic products of the State. The first was on the brownstones; the second on the clays of western Pennsylvania, in which the most important products discussed were the fire clays and pottery clays of that region; the third was on the clays and allied products of southeastern Pennsylvania, the leading products being the kaolins, feldspars and the Philadelphia brick clays. The most important subject treated in the present report is the white clay which is widely distributed over the area.

Permit me to thank you once again for your kind advice during the progress of the work.

Respectfully submitted,
T. C. HOPKINS.

To the President of The Pennsylvania State College.

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# THE CLAYS OF THE GREAT VALLEY AND SOUTH MOUNTAIN AREAS IN PENNSYLVANIA.

By T. C. HOPKINS.

## INTRODUCTORY.

Geographic features.—The area covered by the present report is included in what is known as the Great Valley and the South Mountain regions. The Great Valley is a well marked geographic division which has been recognized since the earliest settlement of the State. On account of its fertile soil and otherwise favorable agricultural conditions, it was one of the earliest settled portions of the State. The first advance of pioneers westward from Philadelphia extended into the small but fertile Chester Valley, known as the Little Valley. The next advance was into the Great Valley, a broad fertile stretch of low land, which, in Pennsylvania, extends in a broad southwest sweep from the Delaware river to the Maryland State line and is a portion of that great valley which extends from New England into Alabama. Portions of it are known by different local names such as the Cumberland Valley, the Lebanon Valley, and the Lehigh Valley. It is crossed by all the large rivers of the eastern portion of the State, the Susquehanna, the Schuylkill and the Delaware. The Lehigh river flows directly across it like all the other rivers but unlike the others, instead of cutting directly through the South Mountain, when it reaches the south side of the valley it flows northeast from Allentown until it meets the Delaware at Easton.

A further interesting feature is that on the south side of the valley east of Cornwall, there are three small streams which rise on the south side of the valley and flow through the sandstone ridge on the south into the Lancaster plain. It is interesting to see the large streams flow through the ridges but it is still more so to see a small stream rise at the foot of a high hill and flow into and through the hill instead of away from it into the valley as one would naturally expect.

There are several creeks of considerable size in the valley, one of the largest of which is the Swatara, one tributary of which rises in the coal basin in Schuylkill county and the other in the Great Valley in Berks county; the two branches uniting in Lebanon county, flow almost across the county in the Great Valley, cutting through the hills on the south side just before reaching the Susquehanna river. In Cumberland county there are two creeks flowing longitudinally in the valley, the Yellow Breeches creek on the south side and the excessively meandering stream Conedoguinet on the north side. The Conococheague creek flows southward along the valley through Franklin county into Maryland.

The valley varies from ten to twenty miles or more in width and includes the area between the South Mountain on the south side and the first fold of the Allegheny Mountains on the north side. The North Mountain has different local names, as the Kittatinny Mountain at the north end and the North or Blue Mountain west of the Susquehanna river. The ridge on the south side is commonly known as the South Mountain, but it is not a continuous ridge and varies greatly in geological structure as well as in topographic features. Its southern extension in Virginia is known as the Blue Ridge.

The counties included in this area are Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland and Franklin. Some notes are given on the clays of York and Lancaster counties which lie south of the South Mountain.

The geological features.—The mountain on the north side of the valley, while known by different local names is structurally one continuous ridge with a comparatively even crest its whole length except where cut through by the rivers or partly cut by wind gaps. The ridge, like most of those of central Pennsylvania, is composed of a highly resisting quartzose Oneida-Medina sandstone of Silurian age. The north side of the valley floor, in places more than half of it, is covered with the Utica-Hudson River slates and shales of upper Ordovician age corresponding to group No. III in the State Survey reports. In Lehigh and Northampton counties this consists largely of slate quarried extensively for roofing, while further southwest it consists of argillaceous shales. The south part of the valley is composed of a compact, blue limestone and intercalary slate of Lower Ordovician age and known in the State reports as group No. II or Trenton, including the Chazy and Calciferous. Investigations by Walcott* show that some of these limestones classed as Trenton are really of Lower Cambrian age. There is apparently no stratigraphical break in the limestone and there is such a paucity of fossils that it has not been possible as yet to draw a dividing line between those of Cambrian and those of Ordovician age and they will be spoken of in this report as the Cambro-Ordovician limestones. Underlying the limestones and forming South Mountain in part, is a series of quartzites, sandstones, and slates, formerly called the Potsdam sandstone, but which Lesley in his final report called the Chickies or Hellam quartzite group No. I, and which Walcott on paleontological grounds classes as Lower Cambrian.

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*Bull. No. 134 United States Geological Survey.

The quartzite and slates form the South Mountains in the southern part of Cumberland county, but they end abruptly near Dillsburg and do not appear again until near Reading, an interval of nearly 50 miles, in part of which there is no ridge on the south side of the valley and in the other part there are bold hills of Triassic or New Red sandstone and conglomerate. Northeast from Reading to the Delaware river, the South Mountain is made up of the Cambrian quartzite and slates and a series of mica and hornblende schists supposed to be of Archean age. There are several areas of the Cambrian quartzites south of the Great Valley in York, Lancaster and Chester counties.

There are several dikes of trap rock in the Great Valley, one cutting the valley at nearly right angles in Cumberland county several parallel with the valley just north of Lebanon and one running diagonally near Reading, but all of which apparently have no relation to the clay deposits.

Clays occur in great abundance and in some variety in each of the groups mentioned, the Cambro-Ordovician limestones being specially rich in both high grade and low grade clays. The Cambrian quartzites and slates of the South Mountain are locally rich in high grade clays. The Hudson River slates contain much clay but it is low grade and but little used. The New Red sandstones contain much shale and clay suitable for the manufacture of paving and building brick.

## Chapter I.

## THE WHITE AND PARTI-COLORED CLAYS.

### General Features.

The most valuable clays in the area under discussion are the numerous deposits of light-colored clays that occur in the Cambro-Ordovician limestones along the south side of the Great Valley and in the Cambrian quartzite and slates of the South Mountains.

The clays as indicated in the title are typically white, sometimes almost snow white, but commonly bluish-white to gray when first mined and turning white on exposure to the weather. Closely associated with the pure white clays are large quantities that are stained more or less by iron oxide forming sometimes a yellow and sometimes a parti-colored, white and yellow, or white and brown clay. In several places there are associated red, black and gray clays that are apparently genetically related to the white clays. These variously colored clays bear a certain resemblance to each other in texture and in their association with deposits of limonite ore. The red clay does not occur in any known locality in sufficient quantities free from the other varieties to have any great commercial value in itself except as a part of a mass of mixed clays. In only a few localities do the black clays occur in commercial quantities, but the white clays and the variegated or mixed ones occur in extensive deposits whose value has scarcely been appreciated as yet by clay manufacturers.

Chemical composition.—The white clays are generally highly siliceous and very "tender" or short-grained, differing considerably in their physical properties from the commercial kaolins of the pegmatite dikes which they resemble in color. The following analyses will give an idea of the general chemical composition. They, like other clays and rocks are subject to many local variations, but they have almost uniformly a high percentage of silica and a comparatively low one of alumina. This may be best observed by comparing the analyses with those of other white clays and kaolins.[*]

Analyses of White Clays and the Original Slates.

| | $Al_2O_3$ | $SiO_2$ | $H_2O$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | Total. |
|---|---|---|---|---|---|---|---|---|---|
| 1. Crude white clay, Upper Mill, Pa., | 9.44 | 84.05 | 2.18 | 0.28 | 0.23 | 1.35 | 2.37 | 0.28 | 100.18 |
| 2. Refined white clay, Upper Mill, Pa., | 17.30 | 73.80 | 4.69 | 0.35 | ....... | 1.18 | 2.49 | 0.20 | 100.01 |
| 3. Mixed white clay, Mt. Holly, Pa., | 17.43 | 73.30 | 4.68 | .37 | 0.02 | 1.28 | 2.99 | .17 | 100.24 |
| 4. White clay, Glen Loch, Pa., | 31.29 | 51.90 | 8.90 | tr. | tr. | 1.52 | 4.01 | 2.99 | ........ |
| 5. Conshohocken, Pa., parti-colored clay, | 26.96 | 59.83 | 9.56 | 1.98 | 0.11 | 0.50 | 0.94 | 0.24 | 100.12 |
| 6. Barren Hill gray clay...... | 26.12 | 60.37 | 5.42 | 0.69 | 0.05 | 1.93 | 5.74 | 0.29 | 100.61 |
| 7. Damourite slate, Fogelsville, Pa., | 34.06 | 49.92 | 6.52 | 0.91 | 0.11 | 1.77 | 6.94 | 0.74 | 100.97 |
| 8. White clay, Fogelsville, Pa., | 21.76 | 72.16 | 4.76 | 0.99 | 0.22 | 0.70 | 3.02 | 2.12 | 105.74 |
| 9. Yellow clay, Fogelsville, Pa., | 22.77 | 64.57 | 4.67 | 5.64 | .40 | 1.28 | 3.25 | 2.80 | 105.38 |
| 10. Damourite slate, Allentown, Pa., | [†]30.30 | 59.30 | 4.70 | [‡] | tr. | tr. | 6.24 | 1.51 | 102.05 |

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[*] See analyses in our report for last year, 1898, II Clays of Southeastern Pennsylvania.

[†] Including iron oxide.

[‡] Nos. 4 and 7 analyzed by Dr. F. A. Genth: Nos. 8 and 9 by J. R. Shimer; No. 10 by P. G. Salom. All the others were analyzed in the chemical laboratory at the Pennsylvania State College.

## Rational Analyses of Pennsylvania White Clays.

| | Sand. | Feldspar. | Anhydrous clay. | Water. | Total. |
|---|---|---|---|---|---|
| 11. Jno. Allen's white clay, South Mt., Pa., | 37.17 | 0.54 | 56.75 | 5.54 | 100.00 |
| 12. Philadelphia Clay Co., South Mt., Pa., | 10.96 | 0.19 | 84.47 | 4.38 | 100.00 |
| 13. Mr. Hoopes, South Mt., Pa., | 51.30 | 2.66 | 42.16 | 3.88 | 100.00 |
| 14. White clay, Latimore, Pa., | 45.52 | 1.31 | 49.77 | 3.40 | 100.00 |
| 15. Damourite slate, Latimore, Pa. | 50.16 | 1.19 | 46.35 | 2.30 | 100.00 |
| 16. Conshohocken parti-colored clay, | 30.46 | 1.62 | 59.90 | 8.02 | 100.00 |

The analyses were made in the Chemical Laboratory at The Pennsylvania State College. The anhydrous clay was determined by difference between the sum of the other substances and one hunhundred.

It will be noticed that the white clays are almost entirely free from iron or any discoloring oxide, but the percentage of alkalies is too high in all cases for a refractory clay. The colored Conshohocken clay (No. 5), has a low percentage of alkalies or fluxing material and can therefore be used as a fire clay where a very high refractory property is not required. The most marked chemical difference between the clays and the original slates from which they are derived is in the higher percentage of potash in the slates. In the alteration from slate to clay part of the potash is leached out.

Origin of the clays.—The white clays are the direct decomposition product of light colored hydromica slates which occur intercalated in the Cambro-Ordovician limestones and in the Cambrian slates, sandstones and quartzites. The preceding analyses show that there is no very marked chemical change in the transition from the hard slates to the soft clays, but that it is a physical change caused by freezing and thawing aided by the action of the meteoric waters in which some of the potash is leached out and the mineralogical and lithological character of the rock changed.

The derivation of the clays from the slates is shown by the manner of the occurrence in a number of openings where there is an intimate gradation from the soft clays to the hard slates. This is shown in the clay pit at Latimore where soft white clay occurs on the outcrop, but is harder and laminated a few feet from the outcrop, and still deeper changes gradually to the hard, nearly unaffected slate. In the old ore pit at Hensingerville the slightly weathered hydromica slate forms the south wall of the pit while the clay mixed with slate fragments occurs at several places in the ore pit. In many of the ore pits in the South Mountains in Cumberland county fragments of undecomposed slate occur interspersed in the clays. The clays nearly always contain numerous fragments of quartzite similar to that found in thin lenticular layers in the slates.

The black clays, which occur in a few places, are in part derived from bituminous slates, and some of them, while probably derived originally from the slates, have been redeposited with considerable vegetable matter in possibly Cretaceous or more recent time. The red and parti-colored clays have been impregnated with iron oxide which has been carried by percolating waters into the cracks of the clay or into the seams of the original slate.

It may be of considerable economic importance to the brick and tile manufacturers to remember that the clay is derived from the slate and that it is probable that the slates, where free from iron, can be utilized in the manufacture of brick and tile as well as the clays. In so far as we can depend upon the few analyses given, the slates are higher in alkalies and hence would fuse more readily, but the temperature of the kilns in burning can be regulated accordingly.

The source of the material of which the hydromica slates are formed cannot be stated so positively, but a probable source is the feldspars, especially the pegmatite veins of the Archean gneisses and schists of the Piedmont belt south of the South Mountains.

Mode of the occurrence of the clays.—The clays occur in somewhat irregular, lenticular deposits of quite varying extent. They were originally intercalated masses or layers of slate in the quartzose, slaty, and limestone rocks but when the rocks disintegrated the clay deposit resulting from the disintegrating slate was subject to noticeable changes in form which was governed largely by the topographical position. Where it occurred on a steep hillside, as the underlying rock disintegrated, the clay would creep down the hillside often for a considerable distance. Where it occurred intercalated in the limestone, as was the case in many places, as the limestone would be leached out underneath, the clay would sometimes run into the channels and fissures so made, and the result would be a complex mass of the clay more or less intimately intermixed with masses of residual yellow clay, ore, chert, and limestone. Where it outcrops on a hillside it frequently works down the slope, mixing with the surface materials and it may veneer the hillside for a considerable distance below the original outcrop. So readily does it spread when exposed to the weather that only in the few places where the inclosing rocks remain intact do we find it confined to its original position.

In very many cases there is a deposit of limonite ore resting on top of or against the clay, rarely underneath it. These ore deposits are frequently quite large and contain a large quantity of valuable ore. It is to the occurrence of these ores that we are indebted for the opportunity of seeing many of the clay deposits that would otherwise be concealed by surface materials. The mining of the iron ores has been carried on quite extensively in some localities for more than 100 years. It was much more active 30 to 40 years ago than it is at present, as the development of the richer ore bodies in other localities has caused a great depression in the ore trade in this region. As a common occurrence of the ore is on the white clay, the removal of the ores leaves the white clay exposed at the bottom or sides of the ore pits, thus making dozens of exposures of the clay shown in both the abandoned and the active iron mines throughout the area.

In a few instances large quantities of the clay were removed in working after the ore, but in most cases very little of it was disturbed as the miners learned by experience that the top of the white clay is in most cases the bottom of the ore. In many places the clay is exposed on one side of the ore pit. Since the ore frequently rests directly upon or against the white clay, the removal of it lays bare the clay and the excavation is then turned in another direction, thus leaving the clay uncovered.

Throughout the Great Valley and in the minor parallel valleys the clay occurs in limestone or residual material of the limestone. In the South Mountain and the North Valley Hill areas it appears to occur in quartzite or schistose rocks. But even here it may have been accompanied in many places by limestones which have leached away and hence do not appear in the explorations. Besides the iron ores, the following minerals occur associated more or less closely with the white clay: Manganese ores, psilomelane and pyrolusite, wavellite, ceruleo-lactite, quartz, chert, and calcite. The manganese ores which occur in the same relation to the clays as the iron ores, have been mined in the South Mountains near Mount Holly and at Ironton, in Lehigh county, while nearly all the iron ores carry more or less manganese. The wavellite occurs in commercial quantities near Mt. Holly and in smaller quantities in the North Valley Hill, north side of Chester Valley. The ceruleo-lactite, a rare mineral, occurs in the ore and clay pits near Glen Loch, Chester county.

As the former exploitations for iron ore revealed large quantities of the clays which were then considered as waste material, the future search for clay may reveal new deposits of ore, which is now almost a waste product in some localities where it was at one time actively worked.

Uses of the white clay.—The clays are adapted to nearly all the uses of any other white clays but the largest markets at present are the paper trade and the potteries. (1) The white clay has been used for a number of years in the manufacture of paper and apparently gives good satisfaction. The points in its favor for this purpose are its pure white color and its very fine texture, which combined with its low specific gravity, cause it to remain in suspension in the paste much better than many other fillers. It is necessary to refine the clay with considerable care when it is to be used in paper-making. Besides the customary process usually employed with clays, it is found necessary in some instances to strain the slip through a very finely woven silk netting which removes all the coarser particles which are not removed in the troughs. Care is likewise needed in the mining operations to remove all the stained portions before washing it.

The following notes by a practical paper maker describes the advantages and defects of clay filling in paper.*

"Kaolin, or China clay, as it is usually termed, is the loading usually employed in the making of views, printings, and the lower qualities of writings. The clay is made into a thin cream with water, generally in a chest fitted with a revolving agitator, so that when furnished to the engine, it will always be of the same consistency. Some paper-makers mix it with resin size, the idea being that in this way it is more firmly held by the fibres, and less liable to pass through the meshes of the machine wire.

"Before running into the beater, it should be carefully strained, so that any sand or unground particles may be kept back. The sieves used for this purpose should be very fine, as even the best grades of clay contain a considerable proportion of extraneous matter.

China clay, in addition to enabling the paper loaded with it to take up the printing ink more rapidly, helps materially in bringing up the surface when calendring, though from its power of absorbing moisture the high finish thus obtained is liable to go back if exposed in a damp atmosphere. Should an excessive amount be added, or if it has been imperfectly strained, the pressure of the calender rolls will have the effect of squeezing the coarser particles out and leaving the sheet pierced with innumerable very minute holes.

"The sizing and feel of clay-loaded papers are never so good as with papers loaded with such materials as pearl hardening (calcium sulphate) or barium sulphate, nor do they bulk so well. Heavy chromo or plate papers often contain as much as 35 to 40 per cent. of clay; and though such a large amount is very apt to cause "dusting" in cutting and printing, the impression obtained is much more clear, and the colors are absorbed more rapidly than would be possible with a smaller proportion of loading."

The following committee report is of interest in this connection:

The addition to paper of mineral matter such as china clay, has the effect of increasing the opacity and improving the texture. Up to a point the advantages outweigh the disadvantages of diluting the fibrous constituents with non-cohesive material. With increase of loading, the sizing agents require to be increased. The committee concludes that 10 per cent. of total mineral matter is the extreme limit for paper for publication of permanent value.*

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*Practical Paper Making. By George Clapperton (paper maker). London, 1894. pp. 58-9.

(2) There are several reasons for thinking that the white clay is well suited for the manufacture of china ware. That it has not been so used in larger quantities is probably due to the fact that while it contains some of the essential constituents of china clay in sufficient purity, it differs from the single ingredients of the ordinary china ware mix. It is unlike the ordinary kaolins in having a lower per cent. of alumina and a corresponding higher per cent. of silica. It lacks the high plasticity of the ball clay. It is not so fusible as the feldspar nor so infusible as the silica. As it thus lacks the characteristic properties of any single one of the ingredients in the ironstone china, the potters are slow to substitute it for materials with which they are familiar. As it simply contains a little more silica than the average kaolin it is only necessary in using it as a substitute for the less siliceous kaolins to increase the quantity and proportionally decrease the amount of silica added. As the other constituents, particularly potash and soda, also vary to some extent, it may be necessary to vary the per cent. of feldspar added. It will thus necessitate a little experimenting with trial batches in order to get the best mixture for any special kind of work. But the comparative freedom of these clays from discoloring metallic oxides would amply justify a little experimenting in this line. When these clays are better developed and there is an abundant supply on the market, it seems quite probable that the demand for them in the pottery trade will greatly increase. The potters are not prone to spend much time or energy experimenting with a material until they are sure that it can be obtained when desired.

(3) The white clay is well suited to the manufacture of encaustic or enameled tiles, especially white tiles. It is so used successfully in one factory, the Penn Tile Works at Aspers. As it becomes better known it will no doubt find a ready market in the tile industry.

(4) Closely allied to its use in the manufacture of tiling is its use for white and ornamental brick and porcelain or enameled brick. One company is using it now for the manufacture of ornamental white bricks for which it gives good satisfaction. The bricks are burned for a long time at a high temperature until they reach a point of incipient vitrification or more properly a stony texture which presents a pleasing appearance in the wall. Outside of the enam-

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*Report of the Committee on the Deterioration of Paper, printed by Wm. Trounce, Fleet St., London, 1898, p. 4.

eled bricks there are few if any others on the market that surpass those in their uniform white color.

There is an important and promising market for these white clays in the manufacture of ornamental brick and terra cotta ware. The demand for these materials is a rapidly increasing one and the product scarcely keeps pace with the demand, because most of the manufacturers who supply the market with bricks are not able to furnish the white clay. Materials of this nature are not widespread, hence the additional importance of these in eastern Pennsylvania which are near the great eastern markets.

(5) Some of the black and parti-colored clays have been used for sewer pipe, terra cotta, stove linings, saggers, and similar purposes.

(6) Almost the entire product of the refined white clay produced by one company is used for calcimining for which purpose it appears well adapted.

The paper trade will probably continue to take the best grade of the white clays as in general it pays better prices than the other industries. The brick and tile markets of the clays can hardly fail to greatly increase. Other uses will probably arise in the course of time as the clays become better known.

## Chapter II.

## DISTRIBUTION AND DEVELOPMENT OF THE WHITE CLAYS.

The greatest development of the white clays is along the Great Valley and the South Mountain areas but they are not limited to this district as they occur also in many of the smaller parallel valleys. They are likely to occur almost anywhere in the area of the Cambrian slates and quartzites or the Cambro-Ordovician limestones. The principal centres of development are Mt. Holly Springs and vicinity in Cumberland county, Mertztown in Berks county, Ore Hill in Huntingdon county, and Glen Loch in Chester county.*

Near Scotland.—It is probable that more or less clay occurs associated with the iron ores at Mt. Alto and vicinity, but I was unable to visit the locality and could not ascertain that any attempt had been made to develop or utilize the clay in any way, except a small quantity shipped to the tile works at Aspers.

Along the base of the mountains east of Scotland and thence south beyond Fayetteville on the Chambersburg and Gettysburg pike there are frequent exposures of the white clay. In one place a drainage ditch two feet deep exposes a mass of excellent white clay. Several wells are said to have been sunk into it, one of which is reported to have penetrated 140 feet into white clay. Unfortunately all the wells in this area were dug a great many years ago when no one was interested in clays and hence the information obtainable now is very uncertain. Very little recent exploitation has been done in this vicinity, although a company has been organized contemplating active development. From an opening north of Fayetteville several car loads of white clay have been shipped to the Penn Tile Works where it was used in making white tile and gave good satisfaction.

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*As this is written word arrives that companies have been organized and work on development begun at Dillsburg and Scotland.

Less than half a mile south of Fayetteville is a sand pit from which a great many car loads of white sand have been shipped. A small quantity of white clay is inclosed in the sand, but no use has been made of the clay. The form of the deposit and the relation of the clay and sand to each other are similar to those in the pit at Mt. Holly Springs.

The few small openings made and the surface exposure indicate a considerable area along the base of the mountains east and south east of Scotland where white clay of good quality occurs. It will require further exploitation to determine the commercial value of the deposits, that is, whether it occurs in sufficiently large quantities free from impurities to make it valuable.

Path Valley.—The Geological Survey reports of the iron mines in Path Valley between Richmond and Fannettsburg mention the occurrence of white clay with the ores in the ore pits, but no use has been made of the clays. The ore pits have been abandoned for a great many years and the clays are almost entirely concealed by the debris.

Near Shippensburg.—White clay occurs in large quantities in the old ore pits a few miles east of Shippensburg. In many of the pits the yellow sand and clay from the surface have run down over and concealed or stained the white clay that was exposed at the time the ore pits were in operation.

The following statements made at the time the pits were operated might be mentioned:*

"In the Big Pond banks, in the southern part of the opening 22 feet of white clay."

"The George H. Clever bank showed white, yellow and red clays associated with wash ore."

"The Muslin bank shows 80 feet of white clay."

Considerable quantities of white and parti-colored clays are now exposed in one of the openings of the Big Pond banks from which a limited quantity has been shipped to the Penn Tile Works at Aspers for use in making encaustic tile. These clays occur at about the same horizon as those near Scotland and at Mt. Holly Springs, that is, near the contact of the limestone and the underlying quartzites.

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*From the An. Rept. Geol. Surv. of Pa., 1886, Pt. IV, pp. 1411-1617.

Mt. Holly Springs.—Extensive deposits of white sand occur on each side of the gap at Mt. Holly Springs and large quantities of it have been shipped to the foundries and furnaces at various points. In one place pockets of white clay occur in the sand, which when first opened were supposed to be extensive deposits of clay and the intention was to mine and use it at the clay factory at Mt. Holly but the pockets were soon exhausted and the clay pit changed to a sand pit. The sand is used in making the white bricks by mixing it with clay from other points.

Two miles west of Mt. Holly on the Stuart tract, white clay was mined for use at the factory in Mt. Holly but the openings were abandoned after a few weeks and have since been idle. As all the clay obtained was mined from shafts which have since been abandoned, the opportunities for examining the deposits of this locality are limited. The clay so far as observed appeared to be less plastic than that from the south side of the mountain, that is, it is not so thoroughly weathered nor disintegrated. It is quite probable that exposure to the weather for a year or so after mining would greatly improve the working properties of this clay. Manganese and wavellite both occur in commercial quantities closely associated with the Stuart clays. The considerable thickness of material overlying the white clays may prove a serious objection to the removal of the clays from surface openings but they are not too deep to remove by subterranean workings. The results from the one or two small openings made are sufficient to justify further exploitation.

Upper Mill.—There is a large deposit of white clay at the old Medlar ore bank just south of Upper Mill which has been operated by the Mt. Holly company since 1898. The chemical character of the clay in this deposit is shown by the following analyses of both the crude and the refined material.

Analysis of White Clay from Upper Mill.

| | Crude clay. | Refined clay. |
|---|---|---|
| Silica, $SiO_2$, | 84.05 | 73.80 |
| Alumina, $Al_2O_3$, | 9.44 | 17.30 |
| Iron oxide, $Fe_2O_3$, | .28 | .35 |
| Water, $H_2O$, | 2.18 | 4.69 |
| Potash, $K_2O$, | 2.37 | 2.49 |
| Soda, $Na_2O$, | .28 | .20 |
| Lime, CaO, | .23 | ........... |
| Magnesia, MgO, | 1.35 | 1.18 |

The white clay is exposed to a depth of about 25 feet on the north side of the old ore bank but there has not been sufficient exploitation to show the extent of the clay body. The surface material was removed from a small area in July, 1899, and the entire face of the clay was being taken away, the inferior portions being dumped into the old ore pit and the cleaner portions sent to the factory at Mt. Holly. Some clay had previously been mined in galleries run in from the face of the bank but the excavations were not carried on with much system or to any considerable distance. Apparently the clay dips to the south at this point and as a considerable quantity of shale fragments appear on the dump of the old ore mine the indications are that the clay changes to slate at no great depth. This might prove an advantage rather than otherwise so far as its use in brick manufacture is concerned. The slate would need grinding but this might prove less expensive than washing the clay, and the slate is less liable to be stained by iron-bearing waters.

Considerable exploitation was done in the area east of the Upper Mill and while clay was found in many places, no large body of white clay was discovered.

Mountain Creek.—Along Mountain Creek between Upper Mill and Pine Grove Furnace there are a number of old iron mines, many of which produced large quantities of iron ore a few years ago and nearly all show more or less white clay which is now being developed at several points.

The most extensive body of high grade clay that has been proven on Mt. Creek is that at the Crane ore bank, one mile above Hunter Run Station, where the Philadelphia Clay Works has mined, washed and shipped clay since 1893. During 1899 the shipments averaged about two car-loads per day or 50 cars per month, at times reaching 25 cars per week. The company pays a royalty of 20 cents per ton, which amounts to nearly 6,000 per year. The clay is mined from underground galleries from what is reported* as an extensive body of white clay on the south slope of Big Mountain. The drift is run in from the edge of the large ore pit where many hundred tons of ore were mined some years ago. The company washed and prepared for market several carloads of the sludge from the old ore washings. There are many thousand tons of this material consisting of clay and sand impregnated with finely diffused iron oxide which was washed from the ores in their preparation for market. It was thought by putting it through the clay washer and thus separating the sand and coarse material, that the product might be used as an ochre, but the project was soon abandoned. The white clay produced at Crane Siding is a superior quality carefully prepared and nearly all goes to the paper factories.

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*The company will not permit any one to visit the mines or the works.

At the Henry Clay iron mine two miles above Hunter Run Station, there is a large deposit of beautiful white clay that is now (1899) being mined and shipped to the clay works at Mt. Holly, where it is mixed with that from the Upper Mill. The mixture is said to give a better clay than either one alone, although analysis of the mixed clays shows a composition almost identical with that from the Upper Mill.

Analysis* of refined clay mixture from Henry Clay and Upper Mill is as follows: $SiO_2$ 73.3; $Al_2O_8$ 17.43; CaO .02; MgO 1.28; $K_2O$ 2.99; $Na_2O$ .17; $Fe_2O_3$ .37; $H_2O$ 4.68.

The clay apparently overlies the ore at this point as it is on the south side of the ore pit and dips to the south, probably due to an overturn of the strata. The extent of the deposit had not been determined at the time that this was written (July, 1899). A drift had been driven into the clay about 50 feet on the south wall of the old ore pit and showed a good grade of clay the greater part of that distance, but in places it is stained to some extent by surface waters carrying iron oxide into cracks in the clay. The developments made so far indicate a productive locality for good clay.

John Allen has mined considerable clay from the hillside a half mile or more east of the Henry Clay pit. There is no ore pit here to indicate the presence of the clay and the mining has been from vertical shafts which are lined with temporary small timbers similar to those used in the kaolin mines in Chester county and elsewhere. Some of these shafts have been sunk to a depth of 90 feet in the clay without striking the bottom of it, but it was found to be too expensive to lift the clay from a greater depth, so the pits are commonly abandoned at about 90 feet and new ones are opened. The clay is hauled by wagon to Mr. Allen's clay refining plant at Henry Clay Station where it is washed and prepared for market. Part of the product is shipped to the paper manufacturers and part to the potteries.

At Laurel, on the H. R. & S. B. R. R., two miles east of Pine Grove Furnace, is a large ore mine in which white and parti-colored clays are exposed. The old ore pit is about 120 feet by 300 feet and 50 feet deep. The ore, which is said to have been near the surface on the north side, is at the bottom of the pit on the south side and runs underneath the clay with a steep south dip. The south face of the pit shows 30 feet or more of clay overlying the ore and overlain in turn by a layer of sand and rock fragments of varying thickness. A considerable portion of the clay is stained by iron and manganese and organic matter, some of it a bright red, some yellow, grayish-blue and black. Intermingled with the colored portions are bodies of white clay. The white, and to a less extent the colored clays have been shipped to the brick works at Pine Grove Furnace, where it is mixed with the "soapstone" and slate in the manufacture of bricks.

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*Made in the chemical laboratory of the Pennsylvania State College; compare with that from Upper Mill.

The Fuller Brick and Slate Company at Pine Grove Furnace has been in operation since 1892 manufacturing plain and ornamental building brick. They use a mixture of the clay from Laurel and black slate for making the red brick and the Laurel white clay and a pale-green "soapstone" for making the lighter colored ornamental bricks. The bricks are dry pressed and are very handsome building bricks. They use two Simpson dry press machines and three Eudaly kilns.

The Penn Tile Works at Aspers postoffice, Bendersville Station, on the Gettysburg and Harrisburg Railroad uses clay from several localities described above along with some from near the works in the manufacture of encaustic floor tile.

Near Latimore postoffice in the north east corner of Adams county, the Central Mining Company has erected a clay-working plant with a view of preparing clay for market. They made an opening for clay near the mill, but not finding it satisfactory they hauled clay from some miles further north in the South Mountains. No clay had yet been put on the market in the summer of 1899 but a number of tons had been washed and dried. It lacked sufficient elasticity to hold together in the cake and would crumble to powder when dry, which is probably caused (1) by the fact that the original slate had not completely disintegrated and hence did not readily separate into the fine clay particles; (2) by the method of washing. They attempted to separate the impurities from the clay by running the slip from the blunger through a silk launder and thence directly to the vats without the aid of flotation troughs. The material observed in the pit at this place by the writer was not very promising for a fine quality of paper-clay, as the slate had not completely disintegrated, but by proper mechanical treatment it might furnish an excellent material for white bricks or tiling. The work is yet in an experimental stage.

South of Boiling Springs, in Cumberland county, in the ore mines of the Reading Iron Company, white and variegated clays in considerable quantities are exposed, but so far as they have been opened they are impregnated with too much iron ore to have commercial value.

West of Dillsburg, in Dogwood Hollow, there is considerable clay exposed around the old ore banks, but so far as shown at present (1899), it is mostly yellow and red clay. However, the ore banks have been idle for so many years that the surface debris may have obscured any white clays which may have originally been exposed.

Proceedings are now under way looking towards the exploitation of these clays.

About one mile west of Dillsburg there are deposits of red and yellow clays associated with the Triassic shales and conglomerates which may prove valuable either as ochres or clays. Test shafts, now filled up, are reported to have been sunk to depths as great as 60 or 70 feet in both the red and the yellow ochres. These deposits occur on the property of Mr. Koontz in the proximity of a bed of limestone conglomerate of Triassic age, which is quarried and burnt into lime. The quarry opening is about 70 feet deep and the character of the rock shows little change in that depth, consisting of a conglomerate with limestone pebbles 6 or 8 inches in diameter, cemented by lime carbonate and red clay. The conglomerate is not so hard, strong or bright colored as the famous Potomac marble of the same age.

No white clay deposits were observed between the South Mountain area of Cumberland county and Montello, in Berks county. The hydromica slates occur in many places in Dauphin, Lebanon and Lancaster counties, but so far as observed by the writer they result in colored clays on disintegration. White clays are liable to occur in this area and may be discovered at any time, but so far none have been made known.

Montello.—On the Hillside, about half a mile south of the Montello Brick Company's plant, at Montello, is a deposit of white clay which promises to be quite productive. It was opened by the Brick Company about 1892 and the product was used for making fire-brick but they found the manufacture of red brick more profitable and soon abandoned the fire-brick industry. The company is this year (1899), reopening the deposit on a larger scale, intending to use it in the manufacture of a light colored paving brick. The white clay belongs to the same general class as the Cumberland county clays. It is a decomposition product of the hydromica slates, fragments of which may be seen in the clay. The inclosing quartzite rock is entirely disintegrated and the surface around the clay pit is covered with sand inclosing fragments of quartzite and sandstone. It is probably not far below the main body of the limestone series which forms the floor of the valley to the north, as there is a large sink hole about a hundred yards north of the clay pit. The present opening is about 100 feet in diameter and 20 to 25 feet deep. Borings are said to have been made to a depth of 40 feet in the clay which show uniformity to that depth; how much deeper is still unknown. In order to avoid the accumulation of water and expedite the removal of the clay, the company has started an open cut on the hillside 20 feet or more below the bottom of the present opening, which will be extended into the clay body. A tramway from the clay pit through the open cut will be extended to the works and the clay transported by gravity.

This clay deposit is probably not an isolated one, but there has not been sufficient exploitation to show the presence of any similar deposits in the immediate vicinity.

Neversink Mountain, Reading.—On the slope of Neversink Mountain almost within the city limits of Reading an opening has been made in a deposit of white clay which occurs in the disintegrating quartzites and slates forming this portion of the mountains. A drift has been run into the side of the mountain from which the clay has been taken, but the mouth of the drift is locked and I had no opportunity to examine it other than from the small quantity of clay exposed on the dump which was a soft white clay containing numerous fragments of quartzite. If it occurs in sufficient obtainable quantities it may prove a valuable deposit, located as it is close to the railways, cities, and coal fields.

Oley township, Berks county.—There is a deposit of white clay at the Hunter ore mine, in Oley township, which produced some clay suitable for the manufacture of paper, but the supply appears to have been quickly exhausted. There has been no work done here for many years and there is no white clay exposed. The only information available concerning this deposit is the following extract from the survey report:*

"Kaolin.—There is a considerable body of kaolin at this (Hunter) mine, consisting mostly of two varieties—a pure white and a buff-colored argillaceous clay, colored with iron. The deposit has been worked under a lease to Theodore Ludwig, of Douglassville, and Squire Manger. The best quality, No. 1, white used in weighting paper, formerly sold at $7 to $15 per ton, and was successfully used at Connard's paper mills at Pleasantville and at Spring City.

"Mr. Burgers, proprietor of the paper mill at the latter place, took the first 100 tons of No. 2 white at $9.00 per ton. Mr. Ludwig divides the kaolin according to quality into three grades: No. 1, white; No. 2, mixed white and yellow; No. 3 buff. He has pretty well exhausted the first quality now, which, he says he got under 6 feet of top covering in a face 30 feet long and 20 feet wide. It showed no persistency, however, and soon pinched out. There is still a considerable amount of buff-colored clay. There were about 800 tons of the three varieties named.

"The kaolin is of excellent quality and deserves further development. A sample of the best that could be found was analyzed by Mr. McCreath with the following result: Silica, 66.170; alumina. 19.890; lime. .260; magnesia, 1.901; protoxide of iron, .783; water 4.784; alkalies and undetermined, 6.211."

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*Second Pa. Geol. Survey, Berks county, $D_3$, Vol. II, p. 367-8.

Molltown.—At Moselem's and Brenig's ore pits a quarter mile east of Molltown, white clay of quite pure color is exposed in considerable quantities, which has apparently never been exploited except some of it was removed as waste material when the ore mine was in operation. The quality and quantity of that exposed would justify further testing of the extent of the deposit with a view of preparing it for market. This deposit is near the top of the Trenton limestone.

Mertztown.—A half mile south of Mertztown is a large clay pit and refining plant which has been operated by the Star Clay Company since July, 1874. During 1899 the company employed about 15 men and shipped the refined clay at the rate of a car load per day.

The pit covers an area of one to two acres and is 50 to 80 feet deep. The overburden of yellow sand and clay varies from 5 to 25 feet in thickness, and on one side of the pit there are bands of pink and purplish-colored clays interspersed in the white to a considerable depth. The mass of the clay is blue to blue-gray when first exposed but quite white when refined and dried. The product is shipped to the potteries and paper factories. The best grade sells at $11 per ton.

Maple Grove (Long Swamp postoffice).—At Maple Grove about 3 miles east of Mertztown is a clay mine operated by Benj. Moore and Co., office in Brooklyn, N. Y. This mine is worked in underground galleries and the clay is elevated by steam power through a shaft said to be 80 feet deep. As the company would not permit any one to enter the mine, no description of the size or character of the deposit can be given. The white clay outcrops in the ditch at the roadside near the mine opening, where it still retains the laminations of the original slate from which it was derived. It is intercalated in the Cambrian quartzites, but it is not known how far below the limestone series it lies.

The clay, after being elevated by steam hoist to the surface, is dumped into a log washer similar to the ore washers, where it is separated from the coarser materials and run through a series of troughs into large settling vats. After the clay has settled, the water is decanted into a separate reservoir and pumped back to the washer. The clay is then removed from the vat to the dry floor where it is dried in the air and then hauled to the refining plant at Hancock Station on the Philadelphia and Reading Railway where it is put through a further process to prepare it for calcimining for which nearly the whole product is used. The dry clay is finely ground on a burr mill and mixed with the proper pigments and other materials and packed ready for market.

The white clays are exposed at many other localities in Berks and Lehigh counties but so far as I could discover none of the other deposits are used commercially.

At Schweyer (Kline's Corners) the white clay has been exposed in two shafts sunk by the Thomas Iron Company, in one of which the clay is said to be 30 feet thick with an overburden of 12 to 15 feet of yellow clay and sand. The white clay is exposed in only one of the ore pits in this vicinity.

In the Ironton ore pits there are large quantities of black clay and some gray and variegated clays. At Orefield, Siegersville, and Guth's Station, black and colored clays are exposed in nearly all the ore pits. As no attempt has been made to use the clays, there have been no developments that would show the extent of the deposits, except as incidentally exposed in mining the ores. The black color is due largely, if not entirely, to carbonaceous matter, and where the clays are free from iron, they will be white after burning, as the carbonaceous matter is all driven off by heat. In several places, however, the clay contains "ore balls," carbonate of iron and some pyrite. In one place native copper was found in small quantities. These clays apparently occur in sufficiently large quantities to justify preliminary testing looking to their use in the industries. It is possible that the iron is local in occurrence or may be readily removed by washing, in which case the clays may prove as valuable as if they were white in the crude state.

Friedensville.—About half a mile southeast of the Friedensville zinc mines is a deposit of white clay in which a shaft has been sunk, it is said, to a depth of 65 feet. The material at the mouth of the shaft, which is now closed up, is a grayish-white, light, powdery clay containing small fragments of hydromica slate. So far as known, no attempt has been made to utilize it, although it has the appearance of being a superior grade of clay.

Little Chester Valley.—The white clays are exposed and have been worked at several points along the north side of the little Chester valley. These occur in Cambrian slates and quartzites near the contact of the limestones of the valley and correspond in age and origin to those described in the South Mountain region.*

The only one of these deposits which has been worked extensively for the clay alone is that north of Glen Loch Station where the Whiteland Kaolin Company has opened a pit and erected a refining plant. The works were not in operation during 1899 and the clay in the pit is partly concealed by the crumbling in of the overburden on the sides. The clay is associated with quartzite and sand, the latter covering the surface around the pit. The limestone is exposed a short distance south of the pit. Considerable quantities of crystallized wavellite occur in the quartzite boulders on the surface, and a rare mineral, ceruleo-lactite, is found in the old ore pit immediately east of the clay. The association of the clay, iron ore, and wavellite is similar to that in the Mt. Holly district.

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*Prof. Carter of the Philadelphia High School informs me that large deposits of clay have been penetrated in some of the well borings in the Little Chester Valley.

About two and a half miles south west from the Whiteland Clay Works, on the north side of the Chester Valley is a large sand and clay quarry which has been in operation for about 30 years. It was formerly operated by James D. Peck, but is now owned and operated by the James D. Peck Fire Sand Company, with their office in New York. The white clay occurs in irregular lenticular masses in the quartzites and sandstones which are partly disintegrated. The quartzite and sandstone boulders are crushed into sand, which is shipped to various points for use in copper and steel furnace bottoms and the clay is used for fire clay. A new crusher and new sheds have recently been erected and a side-track connection made with the Pennsylvania Railroad, thus increasing the shipping facilities. This is one of the best exposures in the State in which to observe the relation of the clays to the quartzites, as both are exposed here in the quarry opening, where the strata stand nearly vertical, dipping about 80 degrees south of east.

At Caln Station, two miles east of Coatesville, on the north side of the Chester Valley, is a white sand quarry operated by Garrison & Co., of Bridgeport, New Jersey. The white sand is overlain by from three to ten feet of yellow sand and rock fragments. The present pit is about 25 feet deep but is said to have been worked to a depth of 60 feet. The sand contains considerable white vein quartz in fragments of varying sizes. There is a sand-washer erected near the quarry where the sand is washed and prepared for shipment to the glass-works and potters. The daily output is about 20 to 25 tons of pure sand. No attempt is made to save the clay which occurs in small lenticular masses through the sand.

On Doctor Beal's property, directly west of Garrison's quarry, large quantities of white sand have been quarried and shipped. There are still other openings further west along the north side of the Chester Valley which have furnished clay and sand to the rolling mills and furnaces of eastern Pennsylvania.

All these deposits along the Chester Valley occur at about the some geological horizon, that is, in the Cambrian quartzites and slates near the contact with the Chester Valley limestone.

Conshohocken.—The clay deposits near Conshohocken were described in last year's report (II Clays of Southeastern Pennsylvania), but at that time their close geological relation to the clays described in the preceding pages was not as clearly recognized as at present. During the present year the study of the clays through the Great Valley shows conclusively a similarity in origin with the Conshohocken clays. However, there is this difference, that the latter (at least part of the deposit), have been subject to water action, in which the clay is mixed with gravel and sand. Most of the Conshohocken clays are probably in or near the position of the original slates from which they were derived. In fact, in one place the clay still retains the lamination of the original slate. The occurrence of the large quantities of gravel and sand lying on and mixed in the upper part of the clay deposits shows that the water has been over this area in comparatively recent times. The age of this last deposit is as yet undetermined. It has some features which indicate the Lafayette stage but there are not sufficient data at hand to establish it.

While they are on the northeastward extension of the Little Chester Valley limestone belt, it may be noticed that the clay deposits are not exactly on the same horizon as those on the north side of the Little Chester Valley, since the latter occur on the north side of the limestone outcrop, while the Conshohocken clays are found in the limestone and near the southern margin of it. However, this difference may be more apparent than real, since the strata are much folded and probably faulted and in most places deeply disintegrated, all of which combined with the absence of fossils, render an accurate correlation of the strata very difficult.

Since writing the report of last year there have been some further developments in the Conshohocken clay district. Mr. Frank Tracy has opened in the old ore bank just south of the school house a clay pit which has been sunk to a depth of 50 feet and produced white, black, red and parti-colored clays similar to that from the other pits. A well was drilled a short distance west of Hallman's clay pit which at the time of my visit, July, 1899, was reported to be 153 feet deep all through sand and gravel. No clay, limestone, nor other rock was found.

Wagontown Kaolin.—The kaolin near Wagontown is a true residual kaolin and belongs in the same class as those described in last year's report, but data were not at hand at that time.

The kaolin is the disintegration product of a pegmatite vein in a hornblende granite gneiss. The vein has a northeast-southwest trend dipping southeast. It was worked to a depth of 75 feet when it was abandoned because of the expense of keeping out the water and removing the very heavy overburden.

Mr. Berry, on whose farm the kaolin occurs, sold the mine to Seneca G. William, who operated it between the years 1877 and 1883. The kaolin was mined by hand and hauled in carts to Cedar Knoll Station on the Wilmington and Northern railway on the banks of Brandywine creek, where a refining plant was constructed and the kaolin washed and prepared for market. It was shipped to the potteries at Trenton and East Liverpool.

So far as I could ascertain this is the only kaolin deposit which has been opened in this portion of the county. It is possible that similar deposits occur in the vicinity but the rocks are deeply disintegrated and the yellowish soil from the hornblende gneiss obscures any kaolin that may occur and it would only be found by systematic search or accidentally by well borings or similar means.

Ore Hill, Blair county—The Springfield mines, at Ore Hill, Blair county, produce large quantities of white clay and limonite ore. The geological relations here are similar to those along the north side of Nittany Valley, where the ore and clay occur on or near sandstones of probably Ordovician age. The clay when first dug has a blue-gray color which whitens on exposure. It forms a massive deposit over an area of several acres. There are numerous openings 25 to 40 feet or more in depth, but since none of these extends to the bottom of the clay the entire thickness of the deposit cannot be seen. The clay is probably formed by the disintegration of the hydromica slates as in the Great Valley district, but the slates are so thoroughly disintegrated that not even fragments of them remain in the clay. However, there are numerous thin streaks of broken white quartzite similar to that occurring in the slates elsewhere. Scattered through the clay are small fragments of gray and black chert, some of which are oolitic. The chert indicates the former presence of limestone which probably occurred intercalated with the slates overlying the sandstone, but in the process of weathering, the limestones were all leached away, the slates disintegrated to clays, and the residual mass including the ore deposits settled down on the sandstone. Both the clay and the ore have been mined here quite extensively for a great many years. During the summer of 1899 there were about 100 men employed on the works. The ore is washed and shipped to the furnaces. Clay in the crude state is shipped to potters and tile manufactures in many localities.

Nittany Valley.—White clay occurs in a number of places through Nittany Valley, in Centre and Huntingdon counties, but so far as known to the writer, no attempt has been made to utilize it even locally. It occurs in limited quantities in the Scotia ore banks and in large quantities in the old Gray iron mines, but in neither place could it be obtained in large quantities free from iron stains. It is reported in several of the ore banks near the northeast end of Nittany Valley.

It is probable that larger deposits of the white clay than those which have been discovered may occur in Nittany Valley, but all the deposits exposed at present are too small and are associated with too many impurities to justify commercial development.

## List of White Clay Producers in Southeastern Pennsylvania.

| No | Name and Address. | Date of beginning | Location of Clay Pits. | Use of Clay. |
|---|---|---|---|---|
| 1. | Star Clay Co., Mertztown, Pa., | 1874 | Near Mertztown, Pa., | Paper and pottery. |
| 2. | Benjamin Moore & Co., | 1892 | Maple Grove, | Calcimine. |
| 3. | John Allen's Clay Works, York, Pa., | .... | Henry Clay Station, | Paper and pottery. |
| 4. | Philadelphia Clay Works, Philadelphia, Pa., | 1895 | Crane Siding, South Mountain, | Paper and pottery. |
| 5. | Mt. Holly Brick and Clay Co., Harrisburg, Pa., | 1898 | Upper Mill and Henry Clay Station, | Brick, pottery, paper. |
| 6. | Central Mining Co., Latimore, | 1897 | Latimore, | Not marketed. |
| 7. | South Mt. Clay Co., Baltimore, | 1899 | Near Dillsburg, | Not shipping. |
| 8. | Penn Tile Works, Aspers, Pa., | 1892 | Near Shippensburg, etc., | Encaustic tile. |
| 9. | Montello Clay and Brick Co., | 1891 | Montello, Pa., | Paving brick. |
| 10. | W. L. Craig, Scotland, | 1899 | Near Scotland, | Not shipping. |
| 11. | The Fuller Brick and Slate Co., Pine Grove Furnace, | 1892 | Laurel Station, | Brick. |
| 12. | Whiteland Kaolin Co., Philadelphia, | 1894 | Near Glen Loch Station, | Pottery. |
| 13. | Henry F. Hallman, Conshohocken, Pa., | .... | Near Conshohocken, | Terra cotta and fire clay. |
| 14. | George S. Keyes, Conshohocken, Pa., | .... | Near Conshohocken, | Terra cotta and fire clay. |
| 15. | Frank Tracy, Conshohocken, Pa., | 1899 | Near Conshohocken, | Terra cotta and fire clay. |
| 16. | American Kaolin Works, Kaolin, Pa., | 1893 | Kaolin Postoffice, | Pottery. |
| 17. | Graham Kaolin Works, Avondale, Pa., | .... | Kaolin Postoffice, | Pottery. |
| 18. | Peter S. Duncan, Ore Hill, Pa., | .... | Ore Hill, | Pottery, tile, etc. |

# Chapter III.

## RED BUILDING BRICK INDUSTRY IN THE GREAT VALLEY.

The clays and shales.—In the Great Valley area the clays suitable for red building brick may be conveniently grouped into three classes: (1) the residual limestone clays; (2) those resulting from the weathering of the shales; (3) the alluvium along the stream courses.

The first of these is the most important in that it is used more extensively than the others which is due chiefly to the fact that it occurs more commonly at points where the bricks are wanted. It is a common saying that anything will do to make red bricks which is in large measure true if we take no account of the quality of the bricks. Since the builders are frequently not very particular about the quality, it is customary to make the bricks wherever there is demand for them. Hence as nearly all the large towns of the Great Valley area are in the limestone portions of the valley, the greater portion of the bricks are made from residual limestone clay. One may see on consulting a geological map of the State that the north side of the Great Valley, covering more than half the area of the valley, consists of the Utica-Hudson River slates and shales, but the narrower limestone portion forming the south side of the valley contains all the large towns such as Easton, Bethlehem, Allentown, Reading, Lebanon, Chambersburg, and Waynesburg, while Harrisburg is partly on the limestone and partly on the shale; further south, Lancaster, Columbia and York are all on limestone areas. In many places the limestone clays make a fairly good red brick but in some places they contain numerous fragments of quartz, limestone, iron ore, or other material in which case an inferior grade of brick is produced. Thus where the quartz fragments occur they make a rough surface to the brick and in burning, the quartz fragments frequently burst and crack or make a protuberance on the brick. The limestone fragments are injurious because they change to quicklime in the process of burning and on exposure to moisture the lime slacks and crumbles out, leaving a hole in the brick. The greatest injury from the ore or any other rock fragments which may be present, is in the lumps, knots or spots which are formed on the face of the brick.

All these injurious foreign materials could be readily removed at slight expense by a simple process of slumming, but this is not done anywhere in the region, so far as I know. In most cases the limestone clays, where free from these rock fragments, make an excellent grade of red brick, but in some instances the clay is too "fat," that is, has too much alumina and not enough sand. The simple remedy is of course the addition of sand. Where this is not done, the bricks become much distorted in burning, crack and twist and shrink greatly in size.

The second group of the clays, those from the shales and slates, are not used very extensively because, as already stated, there are not many large towns on the shale area. While the quality of these clays varies considerably throughout the region, they in most places furnish suitable material for a good quality of red brick.

The third group, alluvial clay, is found in the flood plains along the stream courses, and where it is free from gravel, and does not have too large a percentage of sand, makes one of the best materials for the manufacture of red brick because it is so easily and cheaply prepared for use. For this reason, where it occurs in sufficient abundance, it generally has precedence over all others. At Harrisburg, Reading and possibly other points, there is an upland terrace deposit older than the recent alluvium, possibly representing the Lafayette stage, that is used to some extent in the manufacture of bricks.

Shales.—There is an abundance of shales and slates in nearly all parts of the area suitable for making red brick. The Cambrian slates, those interstratified with the Cambro-Ordivician limestone, Utica-Hudson river slates and shales and the shales of the Triassic or New Red period, all contain good material for the manufacture of brick, but as yet none of them has been used for that purpose except in a few places where they have been used for vitrified brick—(see following chapter).

The Industries.—At Bethlehem there are five brick yards, the largest of which has a capacity of 25,000 per day and manufactures by a stiff-mud process. There are two which manufacture by the soft-mud process and two that make by hand only. The total daily output of all the yards is 75,000 bricks and they employ about 75 men and boys. Three of them use the residual limestone clay; one, the smallest, uses alluvium; and one at the east end of South Bethlehem, uses an old river deposit, that is, material deposited by the river when it was at a higher level that it is now.

At Allentown there are eight brick yards with a total daily output of 203,500 and which employ 205 men. The bricks are all manufactured in soft mud machines excepting those in one yard where they are made by hand. Two of the yards dry the bricks in steam tunnel dryers, while the others dry in racks in the open air. Six of the yards use residual limestone clay, two of them use alluvium from the river bottom, and one uses a mixed material consisting of residual limestone clay and shale combined with some river deposit.

Reading has 9 brick yards employing 197 men and having a total daily output of 164,600 bricks, which does not include the paving or fire-brick factories. There are 18 kilns and 3 soft-mud machines in use. Six of the nine yards manufacture by hand only. The bricks are all dried in racks in the air except in one yard where they are dried in a steam tunnel. The residual limestone clay is used in all the yards except two. In Robinson's yard, Schuylkill and Oley streets, there is a deposit of 4 to 10 feet of yellow-brown clay, containing numerous water-worn pebbles and boulders varying in size from 2 to 10 inches in diameter. The pebbles consist of quartzite and limestone. Underneath the pebbly clay is a light gray clay partly laminated, resting on limestone. This clay deposit is more than 100 feet above the present level of the river and 300 feet above sea level and marks a higher water level at some period in the past not definitely known, but possibly corresponding to the Lafayette stage.

There are several brick yards up the Schuylkill Valley above Reading, nearly all of which use the alluvium from the river valley. The largest of these yards is that operated by Tobias Bros. Co. at Hamburg which has a daily output of 22,000. There were formerly several other brick yards in operation at this point but they are all idle except the one mentioned.

Between Shoemakersville and Bern Station there are two red brick yards in operation, both of which manufacture by hand only. There is another one at Leesport.

At Boyertown, on the east side of Berks county, is a small brick yard having a capacity of 6,000 bricks per day. The clay used is a variegated gray, yellow, and brown residual material which is worked to a depth of about six feet.

At Lebanon there are five brick yards manufacturing red brick, two of which manufacture by hand only and three use soft-mud machines. The total daily capacity of all the yards is 60,000 and the number of men employed is 63. The residual limestone clay is used at all the yards.

At Harrisburg there are three companies manufacturing red bricks, one of which uses shale, while the others use old river deposits, not the alluvium of the present river bottom, but a deposit that marks a higher stage of the water and may possibly correspond to the formation known as the Lafayette. The daily output of the three yards in 1898 was 82,500, while the number of men employed was 97. One of the yards manufactures by hand only, one uses a soft-mud machine and one that manufactures from shale uses a stiff-mud wire-cut machine.

Circumstances prevented me from visiting the brick yards at

Carlisle. The directory states that there are four yards there, operated by J. E. Barnitz, J. Spotts, Spahr Brothers and A. A. Thompson.

Chambersburg has one productive brick yard with a capacity of 30,000 per day; Greencastle has one with a capacity of 10,000, and Waynesboro has two with a combined capacity of 25,000. All of them manufacture with soft-mud machines and all use residual limestone clay. There is one yard in Gettysburg but it was not in operation in July, 1899. It uses a residual yellow clay from the disintegration of the trap rock that is so abundant in various parts of the Gettysburg battlefield.

The city of York* has four brick yards having a daily output of 125,000 and employing 125 men. The bricks are made from a residual limestone clay and are molded on soft-mud machines and burnt in common up-draft kilns.

Columbia has two brick yards, one of which uses residual limestone clay and manufactures by the soft-mud process. The daily output is 20,000. The other company uses shale, the stiff-mud machine, and manufactures a vitrified brick (See Chapter IV).

At Lancaster there are four red brickyards in operation, one of which was opened in 1862, one in 1867, one in 1870, and one in 1872. They all use the soft-mud machine, but a few are made by hand to satisfy a local demand. The daily output of the four yards is 87,000 and 138 men are employed. Residual limestone clay is used and a fairly good quality of brick is produced.

---

*The data for the brick industry at York, Columbia and Lancaster were collected by Mr. L. E. Young, a resident of Columbia and member of the class of 1900 in the Pennsylvania State College.

## List of the Red Brick Yards in the

| Name of Company. | Location. | No. of men employed. | Capacity. | Number of kilns. |
|---|---|---|---|---|
| Groman Bros., | Bethlehem, | 25 | 25,000 | 3 |
| Jas A. Benner, | Bethlehem, | 16 | 20,000 | 3 |
| Aaron Levers, | Bethlehem, | 10 | 10,000 | 2 |
| Henry Irwin, | Bethlehem, | 8 | 5,000 | 1 |
| Stephen Rader, | Bethlehem, | 15 | 15,000 | .......... |
| Swoyer Bros., | Allentwon, | 30 | 30,000 | 3 |
| Taylor Rhodes, | Allentown, | 10 | 5,000 | 2 |
| David W. Mattern, | Allentown, | 25 | 25,000 | 2 |
| Nonnemacher Bros., | Allentown, | 30 | 30,000 | 3 |
| Edwin Kichline, | Allentown, | 25 | 30,000 | 3 |
| C. C. Sensenbach, | Allentown, | 20 | 20,000 | 2 |
| Grim Bros., | Allentown, | 25 | 25,000 | 3 |
| West End Brick Co., | Allentown, | 30 | 30,000 | 3 |
| —— Walters, | Nazareth, | 10 | 8,500 | 1 |
| Daniel Hoch, | Oley, | .......... | .......... | .......... |
| T. D. Bausher & Co., | Reading, | 40 | 22,500 | 2 |
| G. A. Boyer, | Reading, | 7 | 4,800 | 1 |
| G. W. Drexel, | Reading, | 20 | 14,400 | 1 |
| West Reading Brick Co., | Reading, | 25 | 30,000 | 4 |
| C. Kaltenbach, | Reading, | 21 | 30,000 | 3 |
| S. Kline, | Reading, | 28 | 20,000 | 2 |
| W. H. Parker, | Reading, | 11 | 7,200 | 1 |
| Jno. H. Printz & Co., | Reading, | 30 | 28,500 | 3 |
| W. G. Robinson, | Reading, | 15 | 7,200 | 1 |
| Tobias Bros. Co., | Hamburg, | 30 | 22,000 | 3 |
| Sam'l Landis, | Boyertown, | 7 | 6,000 | 1 |
| Peerless Brick Co., | Lebanon, | 15 | 10,000 | 2 |
| John Dressler, | Lebanon, | 20 | 20,000 | 2 |
| Matthias Schwegler, | Lebanon, | 11 | 10,000 | 2 |
| Dan'l Light, | Lebanon, | 10 | 7,000 | 2 |
| Jos. Light, | Lebanon, | 7 | 7,000 | 1 |
| Steelton and Harrisburg Brick Co., | Harrisburg and Steelton. | 30 | 20,000 | 3 |
| May & Reed, | Harrisburg, | 22 | 12,500 | 2 |
| S. L. Bigler, | Harrisburg, | 45 | 50,000 | 3 |
| J. B. Spahr, | Chambersburg, | 15 | 30,000 | 3 |
| Adam Walters, | Greencastle, | 12 | 10,000 | 2 |
| D. B. Johnson, | Waynesboro, | 14 | 13,000 | 2 |
| Haley & Hess, | Waynesboro, | 12 | 12,000 | 2 |
| Edw. Peffer, | Gettysburg, | .......... | .......... | 2 |
| I. Frey & Co., | York, | 35 | 40,000 | 3 |
| Wm. Grothe, | York, | 20 | 25,000 | 2 |
| Benj. Kissinger & Son, | York, | 40 | 35,000 | 3 |
| John Horn, | York, | 26 | 25,000 | 2 |
| The Columbia Brick Co., | Columbia, | 25 | 23,000 | 2 |
| D. F. Gohn, | Columbia, | 25 | 20,000 | 2 |
| Adam Pontz, | Lancaster, | 35 | 25,000 | 3 |
| Jacob Pontz, | Lancaster, | 48 | 30,000 | 5 |
| C. Wise & Brother, | Lancaster, | 25 | 22,000 | 4 |
| James Pranglen, | Lancaster, | 30 | 20,000 | 3 |

## Great Valley Area, Pennsylvania.

| Number and kind of machines | Mode of drying. | Kind of clay or shale. | Date of beginning. |
|---|---|---|---|
| 1 Chambers, | Tunnel, | Res. l. s., | |
| 1 N. H. S. M., | Sheds, | Riv. dep., | |
| Hand, | Sun, | Surface, | |
| Hand, | Sun, | Surface, | |
| 1 S. M., | Sheds, | Res. l. s., | |
| 1 Martin, | Tunnel, | Res. l. s., | |
| Hand, | Sun, | Riv. dep., | 1885 |
| 1 Quaker, | Racks, | Res. l. s., | |
| 1 Martin, | Racks, | Res. l. s., | |
| 1 New Haven, | Racks, | Res. l. s., | |
| 1 Martin, | Racks, | Riv. dep., | |
| 1 S. M., | Tunnel, | Mixed, | 1888 |
| 1 S. M., | Racks, | Res. l. s., | |
| 1 Martin, | Racks, | Res. l. s., | |
| Hand, | | | |
| | Air, | Limestone, | 1886 |
| | Air, | Limestone, | |
| | Air, | Limestone, | 1883 |
| 1 Martin, | Air, | Limestone, | |
| 1 Martin, | Air, | Limestone, | 1888 |
| 1 Martin, | Tunnel, | River dep., | 1887 |
| | Air, | Limestone, | 1845 |
| | Air, | Limestone, | 1883 |
| | Air, | Riv. dep., | 1858 |
| 1 Martin, | Air, | Alluvium, | 1873 |
| Hand, | Sun, | Alluvium, | |
| Hand, | Sun, | Limestone, | |
| 1 Martin, | | Limestone, | |
| 1 Martin, | | Limestone, | 1895 |
| 1 S. M. n. p., | Sun, | Limestone, | |
| Hand, | Sun, | Limestone, | |
| 1 Monarch, | Rack, | Alluvium, | 1898 |
| Hand, | Racks, | Alluvium, | 1887 |
| 1 Big Wonder, | Racks, | Shale, | 1878 |
| 1 Martin, | Racks, | Limestone, | |
| 1 Iron Quaker, | | Limestone, | |
| | | Limestone, | 1878 |
| 1 Martin, | | Limestone, | 1898 |
| 1 Martin, | | Diabase, | |
| 1 Martin, | Racks, | Limestone, | 1885 |
| 1 Martin, | Racks, | Limestone, | 1894 |
| 1 Martin, | Steam, | Limestone, | 1891 |
| 1 Martin, | Racks, | Limestone, | 1899 |
| 1 Chambers, | Steam, | Limestone, | 1894 |
| 1 Martin, | Racks, | Limestone, | 1869 |
| 1 Martin, | Racks, | Limestone, | 1867 |
| 2 Martin, | Racks, | Limestone, | 1872 |
| 1 Martin, | Racks, | Limestone, | 1870 |
| 1 Prangley, | Steam, | Limestone, | 1862 |

## Chapter IV.

## THE VITRIFIED PAVING BRICK INDUSTRY.

The vitrified paving brick industry is assuming considerable proportions in the Great Valley area, although it is yet in its infancy. All of the plants are comparatively new and almost without exception they are constantly increasing their output, as the demand keeps continually ahead of the supply. When one considers the numerous cities and villages in this prosperous region and the poor streets in many of them, it is reasonable to suppose that the demand for vitrified brick will continue to increase. The constantly growing demand for better roads may lead to the use of bricks for country roads. If care is taken to keep the quality of the bricks up to a high standard and equal care is taken to properly drain the road bed and place the bricks on a good foundation, it is questionable if any better pavement can be found for village streets or even country roads where the prosperity of the region will justify it. It is a little more expensive in first cost than a macadamized road but it probably is no more expensive nor even as much so if one considers the quality of the road and the cost of repairs. There is a sufficient quantity of good material in and bordering the Great Valley to pave all the streets and roadways, and it is only reasonable to suppose that there will be an increased activity in the manufacture of vitrified brick until a large portion of the streets and roads is paved with them.

There are four paving-brick plants in the Great Valley, all of them towards the eastern part of it; three near Reading and one near Allentown. The yard at Montello, 10 miles west of Reading, is the most western one in the valley. There are three others near the valley with direct railway communication into it. Two of these are down the Schuylkill valley below Reading and one at Columbia, in Lancaster county.

All of the factories use shale, but not all from the same horizon. Three of them, Montello, Pawling and Oaks Station, use the Triassic or New Red Shale. One, Hamburg, uses the Hudson River shale, and two, Reading and Guth's Station, use shale from the Cambro-Ordovician series.

The Montello Clay and Brick Company's plant is located at Montello, near Sinking Springs, Berks county. It started in 1891 by manufacturing red building brick from the residual limestone clay on a soft-mud machine. But this was soon abandoned and the Triassic red shale was used. The bricks were made by the stiff-mud process and burned to vitrification. The daily output is 50,000, about half of which are used for building brick and half for paving brick. The principal markets are Philadelphia, Lancaster, and intermediate towns.

The bricks are made from the Triassic or New Red shale which is obtained about three miles southwest of the works in the railway cut on the Lancaster branch of the Philadelphia and Reading Railway.

This railway cut is on the divide between the Lancaster plains on the south and the Lebanon valley on the north. There is an unlimited supply of the shale occurring associated with intercalary beds of sandstone and conglomerate which are quarried along with the shale and used for railway ballast and building stone.

The company used some white clay from the mountain south of the works for the manufacture of fire-brick, but this industry was abandoned several years ago. This year (1899) the company reopened the white clay pit for use in the manufacture of white paving brick in order to meet the demand for the same in the Philadelphia market.

A report of the tests on the vitrified brick from Montello will be found in our report for last year.*

The Reading Shale Brick Company began operations in 1896. The plant is located on the Philadelphia and Reading Railway about one mile east of Reading. They manufacture both building and paving vitrified red brick and have a daily capacity of 48,000.

The bricks are manufactured from a yellowish brown shale which occurs inter-stratified in the Cambro-Ordovician limestone. A thickness of 25 to 30 feet of the shale is used, but a well sunk in the yard 130 feet deep is said to show the shale to continue of uniform quality to that depth, thus indicating an unlimited supply. An analysis of the shale which was furnished by the company shows the following composition: Silica, 58 per cent.; alumina, 32.41 per cent.; ferric oxide, 8 per cent.; manganese oxide, 1.5 per cent. The manganese appears as a blue-black stain in the seams of the shales, while the iron impregnates it as a yellowish-brown ferric oxide. The comparatively high percentage of iron indicates rather low refractory power which is further indicated by the glassy appearance of many of the bricks which are burnt to a glassy texture.

At Hamburg the Mack Brick Company manufactures vitrified red brick from the Hudson River shale.†

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*See Clays and Clay Industries of Pa. (II). 1898, pp. 61-62.

†There was no one at the works which were idle at the time of my visit, and particulars are not at hand.

At Perkiomen Junction (Pawling P. O.) the McAvoy Vitrified Brick Company has been in operation since 1894. They manufacture vitrified paving and building brick, the latter being of minor importance. The daily output is 40,000 paving brick, which are shipped to Philadelphia and intermediate points. The material used is the Triassic or New Red shale. A report of the tests of this brick will be found in our last year's clay report.*

At Oaks Station on the north side of the Schuylkill river The Perkiomen Brick Company manufactures vitrified red paving brick, having a daily output of 40,000 bricks which are burnt in a 16-chambered continuous kiln. The material used is the Triassic or New Red shale which is here partially disintegrated to clay. They quarry a thickness of about 20 feet of it, but the supply is practically inexhaustible.

The Allentown Paving Brick Company's plant is located at Guth's Station near Allentown, and has been in operation since 1896. They have a daily output of 18,000 red paving bricks and the material used is a yellowish-brown shale, resembling somewhat the hydromica slates interstratified in the Ordovician limestone. It is not clear from the examination of this single locality, whether the shale at this point is interstratified in the limestone or is part of the Utica-Hudson River beds overlying the limestone. The chief market is Allentown where the bricks are used in large quantities for paving the city streets.

The Columbia Brick Company manufacture vitrified building and paving brick and common red building brick. They began operations April 1, 1894, and have a daily output of 23,000. The principal markets are Columbia, York and Chester counties. The following is a record of the tests of their vitrified brick: Cross-breaking strength, 4,452 pounds per square inch; crushing strength, 20,000 pounds per square inch; impact test (Johnson's), 60 minutes, 24-inch rattler, 5.11 per cent.; absorption of water, 1.09 per cent.

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*Clays and Clay Industries of Pa., II, 1898, pp. 61 and 62.

## Vitrified Paving and Building Brick Industries.

| Name. | Address. | Number of men. | Capacity. | Number of kilns. | Machines. | Material. | Date of beginning. |
|---|---|---|---|---|---|---|---|
| 1. Montello Clay and Brick Co., | Montello, | 152 | 50,000 | 6 | 1 Chambers, 1 Penfield, | Shale, | 1891 |
| 2. Reading Shale Brick Co., | Reading, | 36 | 48,000 | 8 | ............ | Shale, | ............ |
| 3. Mack Brick Co., | Hamburg, | ............ | ............ | 8 | ............ | Shale, | ............ |
| 4. McAvoy Vitrified Brick Co., | Pawling, | 40 | 40,000 | 6 | 1 Chambers, | Shale, | 1894 |
| 5. Perkiomen Brick Co., | Oaks Station, | 40 | 40,000 | 1 | 1 Chambers, | Shale, | ............ |
| 6. Allentown Paving Brick Co., | Ouths Station, | 25 | 18,000 | 6 | 1 Chambers, | Shale, | 1896 |
| 7. The Columbia Brick Co., | Columbia, | 25 | 23,000 | 2 | 1 Chambers, | Shale, | 1894 |

# Chapter V.

## ORNAMENTAL BRICK AND TILE.

A considerable number of the companies, listed under the heading of red building brick in Chapter III, also manufacture a red pressed brick suitable for fronts. Likewise the vitrified brick manufacturers make red front brick. Outside of these there are only two companies manufacturing ornamental building brick in the area under discussion, both of which are in the South Mountain, in Cumberland county.

The Fuller Brick and Slate Company, Limited, at Pine Grove Furnace, Cumberland county, has been in operation since 1892. They manufacture ornamental dry-press brick at the rate of 12,000 per day. They make both the light and red-colored brick, the light-colored by a mixture of clay and soapstone, the red by a mixture of clay and black slate, in both cases the clay serving as a bond, and the soapstone and slate forming the body. The soapstone is quarried from a hill half a mile north of the works; the slate is obtained from a quarry three miles southeast of the works, and the clay is obtained from Laurel Station, two miles down the Hunter's Run and Slate Belt Railway. They manufacture many different sizes and shades of the red, buff and light-colored ornamental building bricks.*

Mt. Holly Brick and Clay Company began operations in July, 1898, with a combined plant for refining clay and manufacturing bricks. The aim is to refine white clay for the potters and paper manufacturers and to use the by-product in the manufacture of ornamental bricks. The brick manufacturing branch of the industry, however, has developed much more rapidly than the clay refining and has overshadowed it in importance. There is an urgent demand in the market at present for white and light-colored ornamental building brick. The Mt. Holly Company is able to furnish the kind of material required and now finds itself taxed to the utmost to furnish it in sufficient quantity. They use a mixture of white clay from Upper Mill and Henry Clay mines, and white sand from the pits near the works. The bricks are manufactured on a stiff-mud, side-cut brick machine having a capacity of 40,000 per day. They are then put through steam-repressing machines and taken to the dry floor, after which they are burnt to the stage of incipient vitrification in Eulaly down-draft kilns. The bricks are burnt for 14 days and allowed the same period for cooling. They more nearly resembled stone in appearance than almost any other brick in the market. They are burnt harder than the ordinary building brick but have not the glassy appearance of many vitrified bricks.

---

*The data were obtained in 1898. The company has no doubt made many improvements since that time.

The Penn Tile Works at Bendersville Station (Aspers postoffice), on the south side of the South Mountains, has been in operation since 1892. They use clays from different points in the South Mountain and manufacture encaustic floor tiling of different colors and patterns.

While the above mentioned are the only companies manufacturing ornamental brick in the Great Valley South Mountain area at the present time, the great demand for light-colored brick, the vast quantities of material suitable for their manufacture, and the comparative nearness to the large eastern markets would all suggest a probably large increase in this industry in the near future.*

## Chapter VI.

## NOTES ON ECONOMIC PRODUCTS OTHER THAN CLAYS IN SOUTHEASTERN PENNSYLVANIA.

In the investigation of the clays it was possible to make observations on many other economic products in the same area, but it was not possible from lack of time, to follow up these observations with a thorough investigation. They are mentioned here in the form of brief notes rather than as an attempt at a thorough discussion.

Graphite.—Graphite occurs at many points in the mica schist areas of southeastern Pennsylvania and is at present mined in four different localities in Chester and Berks counties.

At Byers Station, in Chester county, it has been mined for many years until the works were recently destroyed by fire. The product was shipped to Bethlehem and Reading for use as foundry facings.

A mile east of Chester Springs, Chester county, in 1897, the Philadelphia Graphite Company opened a mine and erected a refining plant which is now producing a superior grade of graphite at the rate of about 2 tons per day. The mineral occurs in two veins, one about 4 feet, the other about six feet thick in a decayed mica schist and forms about 50 per cent. of the vein material which is mined, crushed and worked, the graphite being separated from the rock material in the last process. It is further refined, carefully graded and put into sacks for shipment.

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*The ornamental brick factories in the more southeastern counties were described in our report for the last year, 1898.

At Pikeland, a few miles north of Chester Springs, is an abandoned graphite works and mine. At Boyertown, in Berks county, is a graphite mine said to have been opened many years ago, but it did not prove profitable because no attempt was made to refine the material at the mines and the expense of shipping all the waste material was too great. In 1899 The Boyertown Graphite Company erected a refining mill in which the graphite is separated from the waste material and the industry promises to be profitable.

Near Mertztown, Berks county, a graphite mine was opened 20 years ago and was operated at short intervals by several parties and then remained idle until 1897 when The Penn Graphite Company erected a refining mill and is now producing graphite at the rate of about two tons per day. It occurs in a coarse-grained sandstone in a lenticular vein which is said to have a maximum thickness of 39 feet. The sandstone in which the graphite occurs is so disintegrated that the material can readily be removed with a pick and shovel, no blasting being necessary. The material is crushed in rolls and the graphite separated from the sand by washing and by air currents. The sand is shipped to the foundries for use as moulders' sand.

Garnet.—Near Chelsea, Chester county, are two large garnet mines where common garnets occur in great numbers in the mica schist rock, forming about 75 per cent of the whole mass. The garnets are considerably distorted and irregular in outline, none of them presenting perfect crystal forms. The material is quarried, crushed in rolls, and put through a washing process in which the heavier garnets are separated from the lighter rock material. The product is screened and separated into four sizes and shipped to the office of the company in Brooklyn where it is further separated into 28 sizes and used for making sand paper.

Iron ores.—At one time southeastern Pennsylvania was the centre of the iron industry of the United States and it still contains vast quantities of valuable iron ore, although it has lost its commercial importance by the discovery and development of richer ore deposits in other localities. The two forms of the ore which occur abundantly in this region are magnetite and limonite.

The Cornwall magnetite mine is one of the oldest and most productive mines not only in this region, but in the United States. It is still producing at the rate of about half a million tons per year. There are numerous other magnetite mines in Berks, Chester and Lehigh counties, many of which are now idle and have been for a number of years. There are several mines still producing magnetite in the northeast corner of Berks county, at Red Lion, Siesholtsville, and Mertztown. At one of the mines near Red Lion is a large magnetic separator constructed on the Edison plan. There is another group of magnetite mines near Dillsburg, York county, which were very productive a few years ago, but only one of which is in operation at present, that is the Logan mine, which is producing at the rate of 40 tons per day.

The limonite mines are numbered by hundreds and occur along the entire length of the Great Valley from the Delaware river to the Maryland State line, and in scattered numbers at many points outside of the Great Valley. Most of these are surface pits from which varying quantities of ore have been taken and many of which are now idle and have been for many years. The development of the vast ore deposits in the Lake Superior region and elsewhere has had a depressing effect on these comparatively low grade limonite ores. However, a few of these mines have been in continuous operation and a number of others have been reopened during the past two years since the great advance in the price of iron.*

Cement.—The manufacture of natural rock cement is now one of the most important industries of eastern Pennsylvania. For many years this industry has been carried on profitably at Coplay and Catasauqua and has been constantly growing in importance. There are now (1899) 20 cement mills in operation in Lehigh and Northampton counties in the region about Coplay. Several new mills are being constructed this year and many of the others are enlarging their capacity. Among the new mills recently constructed may be mentioned two at Nazareth, Northampton county, one at Sandt's Eddy, on the Delaware river, one at Egypt, one near Ironton, and one near Molltown, in Berks county.

The rock used in the manufacture of cement is an argillaceous black limestone of Trenton age, which apparently forms a continuous belt along the northern portion of the limestone area of the valley not far from the contact of the Trenton limestone with the overlying Utica slate. It is quite probable that further investigations will show this cement-rock to be much more widely distributed than present developments would indicate.

Slate.—Another very large and important industry in eastern Pennsylvania is the quarrying of slate and its preparation for market. More than half the slate produced in the United States comes from Eastern Pennsylvania from two areas, one the Slatington region in the Lehigh valley, in Lehigh and Northampton counties and the other the Peach Bottom belt in York county on the southern border of the State and extending into Maryland.

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*For description of these limonite mines as they appeared 20 years ago see the various county reports of the Second Pennsylvania Geological Survey; for discussion of the genesis of the ores see paper by the writer in Vol. II of Bulletin of Geological Society of America.

Paint.—The centre of the mineral paint industry of eastern Pennsylvania is in the Lehigh valley north of the slate belt, but yellow ochres are mined at several localities along the Great Valley.

Soapstone.—Soapstone occurs in commercial quantities in several localities in eastern Pennsylvania. The only place where it is quarried at present is at Easton but in past years it has been mined in considerable quantities at Lafayette Station, near Philadelphia.

Corundum.—Corundum is not mined at present in Pennsylvania but it was formerly produced in considerable quantities near Unionville and in smaller quantities at other localities in Chester county.

Chromite.—Chromite occurs at many places in the serpentine areas in Chester and Lancaster counties. It is mined at present near Sylmar, Chester county, and was formerly mined quite extensively at Woods' mine, in southern Lancaster county, and at Chrome, in Chester county.

Copper.—Copper has been mined near Phoenixville, in Chester county, at the Gap Nickel mine, in Lancaster county, which was later worked for nickel, and in the South Mountain region, York county.

Zinc and lead.—Zinc was formerly mined quite extensively at Friedensville, in Lehigh county. Zinc and lead have been mined near Phoenixville, in Chester county, and at several points in Lancaster county. Both metals have been mined in Blair county, near Tyrone.

Building stones.—There is a considerable variety of valuable building stones in eastern Pennsylvania, nearly every class being represented.

White and clouded marbles are quarried extensively at King of Prussia, in the Little Chester Valley, and at Avondale, in the southern part of Chester county. Large marble quarries were formerly operated near Conshohocken and Marble Hall, in Montgomery county, furnishing much of the material for the handsome buildings of Girard College and the hundreds of white marble steps and window sills in Philadelphia.

The limestone through the Great Valley and the parallel limestone valleys furnishes a good rough building stone and is also used quite extensively for burning lime, for furnace flux, and for road metal.

Serpentine has been quarried extensively for building stone at several places in Chester county, but none of the quarries are in operation at present.

The brown sandstone of the Triassic or Ned Red period, which is one of the most important building stones in eastern Pennsylvania, is fully described in our annual report for 1896.

The granites and gneissoid rocks have been used quite extensively for building burposes in Philadelphia, Delaware and Chester counties.

The trap rocks have been used to a limited extent for building stone and in larger quantities for road metal. It is one of the best road-making materials in the State and should be used in much larger quantities than it is at present.

Besides the above mentioned mineral products which add so much to the commercial wealth and importance of this prosperous and thickly settled area, it has a wonderfully productive soil. The Cambro-Ordovician limestones of the Great Valley, the Little Valley, the Lancaster and York county plains, and the nearly parallel belt of the Triassic brownstones and shales, both furnish rich soils which, under the skillful tillage of the thrifty Pennsylvania Germans, rank among the most productive in the United States.

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# ANNUAL REPORT

OF

# THE PENNSYLVANIA STATE COLLEGE

FOR THE YEAR 1899-1900.

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## Part II.

## AGRICULTURAL EXPERIMENT STATION.

Part I contains the Reports of the Departments of Instruction.

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WM. STANLEY RAY,
STATE PRINTER OF PENNSYLVANIA.
1901.

☞The bulletins and reports of the Station will be mailed regularly, free of charge, to all residents of the State who request it, so far as the supply will permit. Address, *Director of Experiment Station, State College, Centre County, Pa.*

Visitors will be welcomed at all times and given every opportunity to inspect the Station in all its departments.

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| JOEL A. HERR, ESQ., | Cedar Springs. |
| H. V. WHITE, ESQ., | Bloomsburg. |
| SAMUEL R. DOWNING, ESQ., | Goshenville. |
| GEO. W. ATHERTON, LL. D., President of the College, | State College. |

HENRY PRENTISS ARMSBY, PH. D., Secretary of the Committee.

## OFFICERS AND ASSISTANTS.

THE PRESIDENT OF THE COLLEGE.

| | |
|---|---|
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| WILLIAM FREAR, Ph. D., | Vice Director and Chemist. |
| WILLIAM A. BUCKHOUT, M. S., | Botanist. |
| GEORGE C. BUTZ, M. S., | Horticulturist. |
| GEORGE C. WATSON, M. S., | Agriculturist. |
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| WILLIAM C. PATTERSON, | Superintendent of Farm. |
| MISS JULIA C. GRAY, | Secretary. |
| J. AUGUST FRIES, B. S., | Assistant Chemists. |
| MILTON E. McDONNELL, Ph. D.,* | |
| ENOS H. HESS, B. S., | Assistant to the Director. |
| CHARLES ALBERT BROWNE, Jr., M. A., | Assistant Chemists. |
| CASSIUS W. NORRIS, | |
| JAMES P. PILLSBURY, | Assistant in Horticulture. |
| MILTON S. McDOWELL, M. S., | Assistant Chemists. |
| CHARLES P. BEISTLE, B. S., | |
| MISS MARY GARNER, | Stenographer. |
| HARRY O WAY, B. S., | Fellow in Agricultural Chemistry. |
| WILLIAM F. WOOD, B. S., | Fellow in Dairy Husbandry. |

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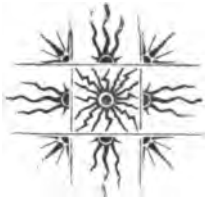
*To October 1, 1899.



# FINANCIAL STATEMENT, 1899-1900.

## A. THE UNITED STATES APPROPRIATION FOR THE UNITED STATES FISCAL YEAR ENDING JUNE 30, 1900.

The Pennsylvania State College Agricultural Experiment Station, in account with the United States appropriation, 1900.

### Dr.

| | | |
|---|---|---|
| To receipts from the Treasurer of the United States, as per appropriation for the year ending June 30, 1900, under act of Congress approved March 2, 1887, ...... | | $15,000 00 |

### Cr.

| | | | |
|---|---|---|---|
| June 30. | By Salaries, ...................... | $13,300 08 | |
| | Publications, ................. | 426 21 | |
| | Postage and stationery, ....... | 89 09 | |
| | Heat, light, etc., .............. | 2 54 | |
| | Chemical supplies, ........... | 299 40 | |
| | Seeds, plants and sundry supplies, ...................... | 13 48 | |
| | Library, ...................... | 75 10 | |
| | Tools, implements and machinery, ....................... | 10 75 | |
| | Furniture and fixtures, ....... | 22 50 | |
| | Scientific apparatus, ......... | 445 39 | |
| | Live stock, .................. | 54 02 | |
| | Traveling expenses, .......... | 251 19 | |
| | Contingent expenses, ......... | 10 25 | |
| | | | $15,000 00 |

State College, Pa., August 13, 1900.

We, the undersigned, duly appointed auditors of the Experiment Station accounts, do hereby certify that we have examined the books and accounts of the Agricultural Experiment Station of The Pennsylvania State College for the fiscal year ending June 30, 1900; that we have found the same well kept and classified as above, and that the receipts for the year from the Treasurer of the United States are shown to have been $15,000.00, and the corresponding disbursements $15,000.00, for all of which proper vouchers are on file and have been by us examined and found correct, thus leaving no balance to be accounted for in the fiscal year beginning July 1, 1900.

H. V. WHITE,
S. R. DOWNING,
Auditors.

Attest: Geo. W. Atherton, Custodian.

## B. TOTAL RECEIPTS AND EXPENDITURES, ALL SOURCES, FOR THE YEAR ENDING JUNE 30, 1900.

### Receipts.

| | United States appropriation account. | General account. | Total. |
|---|---|---|---|
| U. S. appropriation, | $15,000 00 | ............... | $15,000 00 |
| Fertilizer analysis, | ............... | $8,217 00 | 8,217 00 |
| The Pennsylvania State College, | ............... | 15 82 | 15 82 |
| Live stock, | ............... | 1,211 87 | 1,211 87 |
| Seeds, plants, etc., | ............... | 235 07 | 235 07 |
| Excess of expenditures over receipts, | ............... | 5,569 18 | 5,569 18 |
| Total, | $15,000 00 | $15,248 94 | $30,248 94 |

### Expenditures.

| | United States appropriation account. | General account. | Total. |
|---|---|---|---|
| Salaries, | $13,300 08 | $1,566 65 | $14,866 73 |
| Publications, | 426 21 | 369 48 | 795 69 |
| Postage, | 89 09 | 238 18 | 327 27 |
| Heat and light, | 2 54 | 491 67 | 494 21 |
| Furniture and fixtures, | 22 50 | .50 | 23 00 |
| Chemical supplies, | 299 40 | 298 58 | 597 98 |
| Seeds, plants, etc., | 13 48 | ............... | 13 48 |
| Library, | 75 10 | 4 37 | 79 47 |
| Contingent, | 10 25 | 353 99 | 364 24 |
| Traveling, | 251 19 | 163 30 | 414 49 |
| Tools, implements, etc., | 10 75 | 415 06 | 425 81 |
| Live stock, | 54 02 | ............... | 54 02 |
| Scientific apparatus, | 445 39 | 692 45 | 1,137 84 |
| Labor, | ............... | 4,858 72 | 4,858 72 |
| Fertilizers, | ............... | 114 83 | 114 83 |
| Feeding stuffs, | ............... | 925 70 | 925 70 |
| Buildings and repairs, | ............... | 4,755 46 | 4,755 46 |
| Total, | $15,000 00 | $15,248 94 | $30,248 94 |

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

# REPORT OF THE DIRECTOR.

No material changes in the activity of the Experiment Station have occurred within the past year, but the work along the lines of experiment previously undertaken has been continued, although with some interruptions arising from the increasing demands of the work of instruction, both at the College and throughout the State at large through the medium of the Correspondence Courses and the Farmers' Institutes.

*Animal Nutrition:*—The construction of the respiration calorimeter in co-operation with the United States Department of Agriculture has been continued during the year and the apparatus is now approaching completion. The construction of a special building for this apparatus, which was authorized by the Trustees last year, was somewhat delayed on account of necessary changes in the plans, but the building was completed in November, since which time work has been in progress upon the apparatus itself. The building is a substantial, one-story structure 35x57 feet outside, of red Mill Hall brick, with slate roof. The interior walls are all of brick and these, with a steel ceiling, render the building, to all intents and purposes, fire proof. Special care was taken to make the interior of the building as little subject to the changes of external temperature as practicable, the brick walls being double and containing a 4-inch air-space, and all windows being provided with storm sash. Even during the coldest weather of last winter, a very small amount of steam sufficed to keep the building at a comfortable temperature.

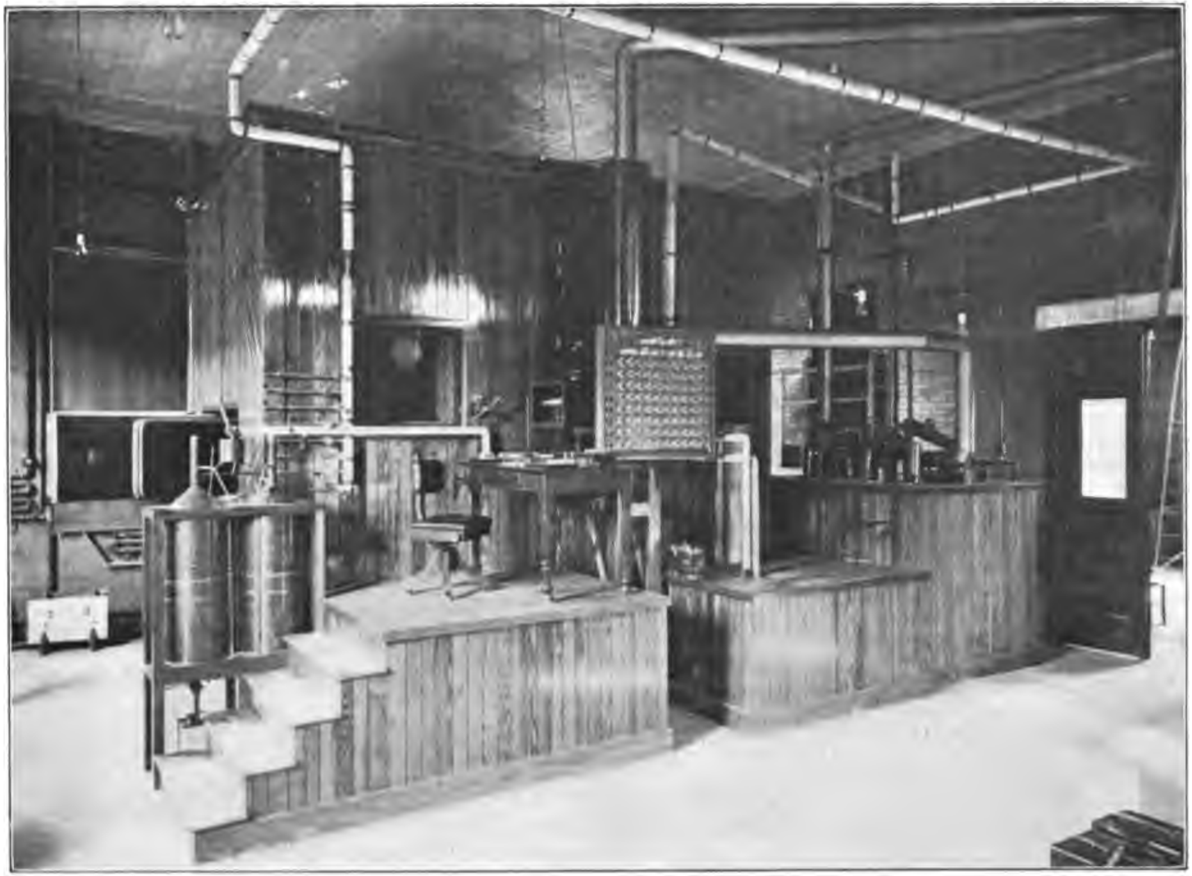
The purpose of the apparatus is to determine the products given off in the respiration of an animal and also the amount of heat produced during the same time. By comparing these with the composition and heat-value of the food consumed, it will be possible to determine with a high degree of accuracy the exact use which is made by the animal of the various elements of its food and how the percentage utilization is affected by various conditions. The apparatus consists essentially of an air-tight box of sheet copper through which is led a current of air whose volume and composition both before and after passing through the box are known. The animal under experiment is placed in this box and the products of its respiration are determined in a fractional part of the air current just mentioned. In addition to this, a current of cold water, passing through a series of copper pipes in the box, serves to carry away the heat given off by the animal, the amount of which is measured by the weight of the water and its increase in temperature. The remainder of the apparatus consists of ingenious and somewhat complicated devices for preventing any loss of heat through the walls of the chamber or in the air current. All these things involve a vast amount of detail and the construction of the apparatus has necessarily appeared somewhat slow. It is now anticipated, however, that test experiments can be made with it at an early date.

During the year, an experiment pertaining to the economy of different methods of watering and handling fattening steers has been carried out, in co-operation with the State Department of Agriculture, by the Agriculturist of the Station. This experiment has been conducted at the College barn in a most satisfactory manner. As two or more car loads of steers are annually fattened on the College farm, it will be desirable to repeat this experiment on a larger scale in following years and to solve, if possible, some of the practical questions relating to the feeding of fattening animals which now confront the farmers who depend upon fattening steers each year to maintain the fertility of their farms.

*Agricultural Chemistry:*—The chemical work of the past year has been to a large extent similar to that of previous years. The two main divisions of this work are the work of fertilizer and food analysis for the State Department of Agriculture and the check work required by our own investigations in the field and stable. In addition, a considerable number of samples of various sorts have been received for analysis.

As in the preceding years, the work connected with the State Fertilizer Control has been the most prominent part of the chemical work. For the season ending July, 1899, there were analyzed in this connection four hundred and three (403) samples and in the fall of 1899 three hundred and thirteen (313). In addition to the care of the chemical work and valuations, for which, as in past years, the Chemist of the Station was responsible, the Chemist was also called upon this year to prepare the Department bulletins presenting the results of the work.

In addition to the routine work above noted, a considerable amount of work of investigation has been carried on during the year under the direction of the Chemist of the Station, including a study of the mechanical and chemical composition of three bench soils for roses; a study of dried distillery waste; a chemical study of the humus in the soil of certain of the plots of the general fertilizer series; and a study of methods of cattle food analysis for the Association of Official Agricultural Chemists.



General View of Respiration—Calorimeter.

A considerable amount of chemical work has also been undertaken on behalf of the State Department of Agriculture by members of the Station force, including a study of the chemical and mechanical effects of lime upon typical Pennsylvania soils; a study of the chemical composition of the apple and its products; and a study of the changes which cider undergoes in its conversion into vinegar. Investigations are also in progress upon the composition of the crude fiber of cattle foods, upon certain constituents of the urine of domestic animals, and upon the use of the bomb calorimeter for the determination of sulphur and phosphorus in organic materials.

*Field Experiments:*—The work in this Department during the past year, under the charge of the Agriculturist, has consisted chiefly in carrying out the plans of experiments that have been in progress for a number of years. While experiments designed to test the efficiency of new methods and the utility of comparatively new plants have not been ignored, yet the larger share of our attention has been given to carrying on the somewhat extensive fertilizer tests which have been in progress for more than sixteen years and the variety tests of wheat, oats and potatoes. The fertilizer tests include each year thirty-six plots each of four crops—wheat, grass, corn and oats—the plots of each crop receiving twenty-four different kinds of treatment as regards the application of fertilizers. As this experiment has now been conducted through sixteen years, or four complete rotations of four years each, the data obtained from the average yields of the various plots furnish most interesting information and will be the subjects of forthcoming bulletins.

The variety tests of wheat, oats and potatoes have furnished interesting results, showing that, under uniformly good conditions, the yield depends more largely upon the kind and quality of the seed than is generally supposed by the practical agriculturists of the State.

For three years, tests have been made of seeding land to crimson clover. Heretofore, the Station has been called upon to advise the farmers as to the best time of sowing this seed without having made practical experiment. These tests have each year given corroborative and decided results.

Various soiling crops have been grown with a view of comparing their feeding value, as well as to test the ease of production on the somewhat heavy clay soil of the Experiment Station Farm, which fairly represents a large proportion of the soil of central and southeastern Pennsylvania.

The field experiments with fertilizers upon tobacco in Lancaster and Bradford counties have been continued from previous years in charge of the Chemist of the Station. A partial report was made last year upon the field results and a similar report upon other phases of the work is in preparation.

*Dairying:*—A large share of the time of the Dairy Department has been taken up with the work of instruction and it has not been found practicable to initiate any extensive researches, but incidentally, in connection with the work of the Dairy School, a number of tests of separators have been made. A series of experiments has also been begun upon the question of moisture in butter in the hope of getting more light upon the influence of various conditions in determining this important factor, and some experiments upon the manufacture of dried curd are planned.

*Horticulture:*—In our trial grounds we have maintained the plantations of the several small fruits, testing the many varieties which are sent to us from time to time by our patrons. An experiment upon whole and piece root apple grafts is in progress and the trees are making satisfactory growth, but a long period of years will be required to observe any permanent effects of the two systems of propagation. An experiment in Ginseng culture is progressing to our satisfaction, and in a few years more the young roots planted will have reached maturity in our lattice house.

Considerable alarm has been aroused by the growing prevalence in our State of the disease of nursery trees known as crown gall. Our efforts in the past two years to find a remedy have not yet been successful on account of the difficulty of causing the disease to develop in our soil, but experiments have now been inaugurated upon a nursery where infected soil is known to exist, and various remedies are being tried there.

*Publications:*—The following bulletins have been issued during the year: No. 46, Variety Tests of Wheat; No. 47, Tests of the Sugar-Beet in Pennsylvania; No. 48, Winter vs. Spring Wheat Bran; No. 49, Field Fertilizer Experiments on Tobacco; No. 50, Distillery Waste, Miscellaneous Cattle Food Analyses. As noted in the last Report, the present plan of publication contemplates comparatively brief popular bulletins, freely distributed, while the Annual Report, of which only a limited edition is printed by the State, is intended to be somewhat more technical in character and to constitute the place of ultimate record for the results of experiments.

The mailing list of the Station has been revised during the year. With Bulletin No. 46, a request was sent out for acknowledgment from those who desire subsequent bulletins. Approximately 8,000 were thus acknowledged and the names of those responding have been entered on the new mailing list.

The correspondence of the Station during the years has been quite extensive, covering the usual variety of subjects. In all approximately 5,000 letters have been received during the year.

*Personnel:*—But few changes have occurred during the year. Dr. M. E. McDonnell, who had been connected with the Station since 1893, resigned October 1st to accept a position as Bacteriologist of the Pennsylvania Railroad. Mr. A. N. Diehl terminated his engagement as Assistant Chemist at the close of last year, and the Fellowships in Agricultural Chemistry and Dairy Husbandry were filled by the appointment respectively of Messrs H. O. Way and W. F. Wood, graduates in the class of 1899. Both these gentlemen resigned during the year, however, to accept more lucrative positions on large farms.

*Library:*—The library of the Station is being catalogued in accordance with the modified Dewey system as proposed by the Librarian of the United States Department of Agriculture. It now contains about 1,300 volumes, consisting largely of technical periodicals, particularly foreign, and of the reports and bulletins of other Stations.

*Needs of the Station:*—The farm equipment of the Station is in urgent need of some additions and improvements to bring it up to the standard of the best farm practice, which it ought unquestionably to maintain. During the past year, a stave silo of a capacity of about 110 tons has been added to our farm equipment. We should, however, have a second one in order to furnish a liberal supply of silage to our dairy herd. In addition to this, there is urgent need for a suitable implement and tool house, a piggery with facilities for experimental work, and a poultry house with accommodations for incubators and brooders. The barn yard, which is now partly roofed, should be brought entirely under roof, and the cow stable should be re-arranged and properly floored to prevent waste of manure. For the proper development of the horticultural work of the Station, a green house or houses especially for experimental work is also an indispensable requisite.

As I have pointed out in previous reports, the State makes no appropriation for the current work of the Station and during the thirteen years since the establishment of the Station has appropriated but $19,000 for equipment. Other States inferior in wealth and resources to Pennsylvania have, on the other hand, liberally supplemented the Hatch fund by State appropriations and as a consequence their Stations are carrying on a range and variety of work which is impossible for us under present conditions. This fact, I believe to be worthy the serious attention of the Board of Trustees and of the State. Even a very moderate addition to the annual income of the Station would make a vast difference in the amount of work which it would be possible to undertake. We have men competent to carry on examinations and researches which would be of great benefit to the agriculture of the Commonwealth, but at present we lack the means to make the most efficient use of these men. As a measure of true economy, they should be relieved so far as possible from the mechanical and clerical details of their work which now consumes too much of their energy and be abundantly furnished with all the apparatus and equipment necessary for effective work.

# THE AGRICULTURAL USE OF LIME.

BY WILLIAM FREAR.

## I. USE OF LIME UPON PENNSYLVANIA SOILS.

The use of lime as a soil amendment prevails more extensively in Pennsylvania than in any other portion of the United States. The theories and methods of practice differ quite widely, however, in different portions of the State and there is constant request for information upon the various points of practice. To meet this demand the writer was, with the approval of the Advisory Board of this Station, commissioned by the Secretary of Agriculture of Pennsylvania to conduct an inquiry into the practice of liming in the several counties of the State and to make a series of laboratory investigations upon the effects of lime upon typical soils of the State that were found in farm practice to respond well to applications of lime and upon the relative influence of magnesia as an amendment—this last topic taking its importance from the prevalance of highly magnesian limestones in many parts of the Commonwealth.

The inquiry was made with aid of many public spirited correspondents in the various counties and in neighboring States; in the compilation of limestone analyses the details of the work were performed by Mr. C. A. Browne, Jr. The laboratory investigations were carried out in the laboratories of the Station and with the aid of my assistants: Messrs. W. S. Sweetser, M. S., and M. S. McDowell, M. S., upon the effects of lime and magnesia upon the nitrogen and organic matter of the soil; and Messrs. C. W. Norris and C. P. Beistle, B. S., upon their effects upon the physical charcter, acidity, carbonatation and the condition of the potash and phosphoric acid of the several soils. The several soil samples were obtained through the interested co-operation of Messrs. L. W. Lighty, Hon. S. M. Wherry, John Moyer, J. S. Biddle, Ed. Anderson and Joel A. Herr. To each of these gentlemen the writer is under much obligation.

The results of the inquiry and investigation are presented as Bulletin No. 61 of the Pennsylvania Department of Agriculture and, since the scientific work has been performed by officers of this Station exclusively, are, with the kind permission of Hon. John Hamilton, Secretary of Agriculture, incorporated in this report.

## HISTORY OF LIMING.

The use of lime, or "burnt lime," as it is sometimes called, as a means of increasing the productiveness of soils dates back for many centuries. Existing evidences indicate that other calcareous substances, such as marl and wood-ashes, were used as fertilizers in a number of localities long before lime itself was employed for a similar purpose. The most ancient writers of Europe dealing with agricultural processes, refer to their use. Pliny (died A. D. 79) speaks of the application by the Greeks of marl to certain heavy soils as though the custom were one long known, and the Roman general, Varro (died B. C. 28), describes the applications of marl practised by the peoples dwelling in Britain and Gaul.

A. Dickson,* who has made a careful study of the Greek and Latin writers, asserts that lime was not used for agricultural purposes until about the time of Pliny, although its property as a mortar-making substance was well known long before. Cato (died B. C. 150), who wrote of the agriculture of his times, is, however, quoted by Loudon,† as follows: "If you cannot sell wood and twigs, and have no stone that will burn into lime, make charcoal of the wood, and burn in the corn (grain) fields the twigs and small branches that remain." Cato also gives a careful description of the construction of a lime kiln, which was apparently of the type known to-day as a "flame kiln." Loudon infers from the passage quoted that the lime was to be applied to the land, but it is not a necessary conclusion; the use of the waste twigs and faggots to yield wood-ashes for application to the land, in case they cannot be sold or better used for burning lime, is the only distinct recommendation contained in the sentence.

The application of lime was, in Pliny's time, confined by the Roman farmer chiefly to his vineyards and olive orchards; it was also quite a good deal used to hasten the maturity of fruiting of the cherry; but as to its use for ordinary farm crops, while it was occasionally practised, there is no indication that the practise was at all general.

The Chinese, whose civilization stretches away beyond historical records, and whose agriculture is, in many ways, very advanced, esteem wood-ashes as the very best of manures. While they are aware, says Loudon,‡ of the fertilizing value of lime, they use it chiefly for the purpose of destroying insects.

During the Dark Ages following the decay of Roman civilization, social and political confusion almost entirely suppressed intensive and skilled agriculture, except as its best traditions were here and there preserved by the studious inmates of an occasional monastery; of this period, there is little agricultural record. It is clear, however,

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*Husbandry of the Ancients, 1807, I, 230.
†Encyclopaedia of Agriculture, 6th ed., 1869, p. 25
‡*Op. cit.*, 161.

that the practice of liming had meanwhile been more or less continuously kept up. Sir Anthony Fitzherbert, the first prominent English writer on agriculture, in "The Book of Husbandry" (London, 1523) strongly urges the use of both lime and marl; and Gervase Markham, in "The Countrey Farme" (London, 1616), which is chiefly a compilation from the French, Italian and Spanish writers of the sixteenth century, mentions lime as an important addition to many garden soils and, for general cultures, to cold soils in particular.

Since those days, the application of lime has been continued in all those European countries where agriculture exhibits the highest degree of advancement, though with great differences in the manner of use to which reference will later be made in the discussion of the various more important practical questions concerning liming. More particularly has the practice obtained in Scotland, Wales and the northern and western counties of England—that is, in the more humid regions.

In a private letter, Prof. R. Warington, of the University of Cambridge, long chemist to the Rothamsted Experiment Station, says: "Before the introduction of artificial manures, lime was, next to dung, the commonest manure employed by farmers in England. The use of lime has, in recent years, much diminished. A return to the former practice would be, in some cases, decidedly beneficial. * * In this neighborhood (Rothamsted) in which the subsoil of the fields is chalk, it was a common practice to sink pits into the subsoil and to spread over the fields the chalk brought up from below. * * The analysis of the Rothamsted soil shows that the first nine inches contains about five times as much lime as the second or third nine inches, a relation most unusual in the case of natural soils, and arising apparently from the ancient application of chalk to the land."

In Belgium, in those regions in Germany where the heavier soils prevail, and in France upon the lighter granitic soils, it is also much used.

Dehérain* states the revival of the use of lime in France did not, in all probability, occur until the beginning of the seventeenth century, and quotes from Oliver de Serres, *Theatre d' Agriculture* (I, 127), to the effect that its use had been followed for a long time in the districts of Gueldres and of Juilliers. At the present time, Dehérain states, the use of lime and of marl has wrought a veritable agricultural transformation in Mayenne, Sarthe, Limousin and Sologne.

It was naturally among the first materials which the European settlers in the New World used when bringing into tillage soils requiring especial treatment, such as swampy lands and very heavy clays. John Spurrier, in "The Practical Farmer" (Wilmington, Del., 1793, a subscription book numbering among its subscribers "George Washington, Esq., President of the United States"), one of the earliest American works on agriculture, treats quite fully of the value of lime in the amendment of such soils and shows a practical acquaintance with the results of its use, though, like other writers of the period, he offers very quaint theories to account for its action. Prior to the introduction of the modern commercial fertilizers, the common calcareous manures were very largely employed. In Canada and in New York and Pennsylvania, gypsum, or land plaster, was a very common application; where marls were readily accessible, especially in Canada and New Jersey, they were widely used and, despite their bulkiness and the great cost of their transportation, they were often carried many miles by rail for application to general farm lands. Wood ashes have been employed everywhere, Canada ashes still finding a large sale in the New England States, New York and northern Pennsylvania. Leached wood ashes, composed chiefly of carbonate of lime, are much used in New England. The use of burnt lime was especially prevalent in Eastern Pennsylvania and New York; in certain localities, however, such as Eastern Massachusetts, it is scarcely used at all; its difficult accessibility is not the reason for its disuse in many of these localities.

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* Traite de Chimie agricole, 516-7.

The introduction of commercial fertilizers, particularly the acidulated lime phosphate, potash salts and soluble nitrogenous fertilizers, greatly affected the use of lime in New York and Pennsylvania. While there are many farmers firmly fixed in the traditions of their fathers, who have clung to the use of stable manure and liming to the total exclusion of the artificial fertilizers, they were more numerous who dropped lime almost entirely out of consideration as a means of soil improvement, and the traveler will see in all those regions where lime was formerly used by all farmers, dismantled lime-kilns on every hand.

This tendency to exclude liming has, however, been strongly combatted; the question of "lime *versus* phosphates" has been mooted in some way or other at nearly every farmers' institute held in the State, with the expression of highly divergent experiences with the contrasted materials and still more highly divergent theories of their several actions. The writer has been led to believe that, without at all diminishing the importance of the place assigned to the commercial fertilizer in farm practice, the use of lime is coming into renewed favor, and is gradually becoming more general. Many inquiries made of the writer, and many statements made by Pennsylvania farmers indicate, however, that the subject is one upon which much confusion of opinion still exists. Nor is this peculiar to Pennsylvania..

Storer* says: "As matters actually stand, the student is met at the threshold of the inquiry by so many different statements, so many possibilities and probabilities, that the subject is made to seem less clear than it really is. As has been said, the contrast between the current methods and practices of farmers in respect to the use of lime, are very remarkable. Why is it, for example, that so little lime is used in eastern Massachusetts, and why is it that such enormous quantities of it are used in other districts such, for example, as some parts of Pennsylvania, of France and of Germany? Indifference towards lime, or objection to it, is by no means peculiar to this particular locality. It is notorious that in some parts of the world landlords have often absolutely forbidden their tenants by contract from using lime, and the employment of it in agriculture at the present day cannot in any sense be regarded as a general practice."

## LIMING IN NEIGHBORING STATES.

Before entering upon the consideration of Pennsylvania practice, a brief view of that of neighboring states will be of interest.

In Rhode Island, as a consequence of careful investigations made at the Rhode Island Experiment Station, the use of lime upon sandy upland soils has grown very rapidly, although it is only of recent date.

Hon. Geo. T. Powell, of Ghent, N. Y., well known to Pennsylvania farmers as an institute lecturer, writes: "There is no lime used in eastern New York." Dr. L. L. VanSlyke, of the New York State Experiment Station, virtually endorses this statement.

Of the practice in New Jersey, Prof. E. B. Voorhees, Director of the New Jersey Experiment Station, writes, that about one-third of the farmers in the northern and central sections follow it, but the use is decreasing. The quantity used is about the same as formerly, viz: 25 bushels of stone lime per acre, applied once in each period of four or, more commonly, five years. It is most frequently applied to wheat at the time of seeding, being spread after plowing and harrowed in. The lime is sometimes home-burned, but is generally purchased from dealers at a cost of 9 to 13 cents per bushel, and is hauled by the farmer for a distance of two to six miles. It is not allowed to stand in small heaps before spreading. Its best results are seen upon upland clays and shales.

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*Agriculture, 4th ed., Vol. II, p. 139.

As to Maryland, Director H. J. Patterson, of the Maryland Experiment Station, says that the use is confined to certain limited sections of the State, and appears, in some localities, to be on the increase. The lime is applied once in eight or ten years to land that it seeded down to grass; the amount applied is commonly fifty to seventy-five bushels, but only twenty to twenty-five bushels in some localities, and there is a general tendency toward the lighter applications. The application is commonly made after plowing, and the lime harrowed in; in some sections, top-dressings on wheat and grass are considerably practiced. The lime is not often allowed to stand in small heaps before application. Both oyster-shell and stone lime are used. Some farmers burn their own lime, but it is, for the most part, purchased of dealers in Pennsylvania, and in Washington, Frederick and Baltimore counties, in northern and northwestern Maryland. The cost at the kiln or warehouse is 8 to 12 cents per bushel, and the distance the lime is hauled is about six miles on the average, a haul of twelve to twenty miles being not infrequent. The effect of the application is especially noticeable in the improved growth of grass and clover, these plants often failing entirely when lime is not used.

Of West Virginia, Prof. L. C. Corbett, of the West Virginia Station, writes that in those sections where lime is easily produced by home-burning, about 10 per cent of the farmers follow the practice, but scarcely 1 per cent. in other sections. The lime is usually home-burned, but the limestone is occasionally hauled two to five miles. The quantity applied is not closely estimated, the abundance increasing as the cost of the lime is less, and one application serves for many years. The application is made directly from the wagon upon plowed ground, and the lime harrowed in. The river bottom soils are never limed, only the heavy clay uplands receiving the application.

In Ohio, says Director Thorne, of the Ohio Agricultural Experiment Station, the use of lime as a means of soil amendment, is very rare.

Leaving the humid regions and turning to the States possessed of a more or less arid climate, Prof. E. W. Hilgard, Director of the California Experiment Station, says of California: "Liming and marling are scarcely at all practised in this State, owing to the fact that nearly all the soils at present cultivated contain an excess of calcic carbonate, manifested either by effervescence with acid or the blueing of litmus paper after twenty minutes. The average lime content of California soils, as determined by extraction with hydrochloric acid, is over 1 per cent., and the character of the vegetation is almost throughout 'calciphile' (lime-loving). In a few cases where very heavy clay soils have been found poor in lime, I have recommended the use of quick-lime or marl, and it has been done with very good effect; as, also, at a few points in the 'tule' lands—coast marshes—bearing sour grasses. But even in these acidity is rather the exception than the rule, on account of the large proportion of lime contained in the river alluvium."

Speaking of the United States at large, Prof. I. P. Roberts* estimates that at least 99 per cent. of the arable land has never been limed, and is not likely to be in the near future—partly because lime is inaccessible, partly because the soils of certain great areas do not require it.

## PRESENT PENNSYLVANIA PRACTICE.

As an introduction to a discussion of the principles involved in the practice of liming, it has been thought that a careful survey of the extent and manner of its use in the several portions of the State would be valuable.

Accordingly, two series of questions were framed to cover the more important points of practice, and submitted respectively to a number of well-informed farmers in each county of the State, and to those lime dealers and burners whose addresses could be secured. The writer is indebted to a large proportion of the gentlemen to whom these queries were addressed, for their full and careful replies. From these replies, the statements that are given below of the practice in the various portions of the State have been compiled. The names of the several correspondents who have given this valuable assistance are given in Appendix A.

### *Varying Extent of Practice.*

The proportion of farmers in the several counties who use lime has been reported by the correspondents. The answers from the same county are often quite divergent, owing doubtless, to the fact that because of differences in local conditions, one section of a county uses lime more than another. Necessarily, the number of correspondents from each county was too small to give a perfectly true representation of the extent to which lime is used. The percentage of farmers in each county who use lime upon their soils, whether with frequency or not, as gathered from the correspondence, is shown upon the accompanying map. When a percentage of less than five was reported, the use was considered as probably experimental and no representation made for it.

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* The Fertility of the Land, 1897, p. 306.

Of the sixty-three counties reporting, sixteen show no use of lime; in ten or more, it is used by only a few farmers, and in ten or more, by less than half, while in eleven it is said to be used to some extent by 75 to 100 per cent. of the farmers. The greater use is found in the eastern and southern parts of the State; with a few marked exceptions, the least on the extreme northern and western borders. As will be seen in a later presentation of the cost of lime in the several localities, one reason for its lack of application there is the great expense. From this showing, it is very probable that the use of lime is far more prevalent in Pennsylvania than in any other American locality.

The above statement gives no just notion of the soil area to which lime is applied. The surface of Pennsylvania is greatly broken into mountain, ravine and broad river valley. The rocks from which its soils are formed represent most of the well-known geological formations of North America. There is, in consequence, an almost bewildering variety of soil. The use of lime in each locality is largely restricted to specific kinds of land and no data are readily accessible to permit an estimation of the total farm area of Pennsylvania upon which liming is practised.

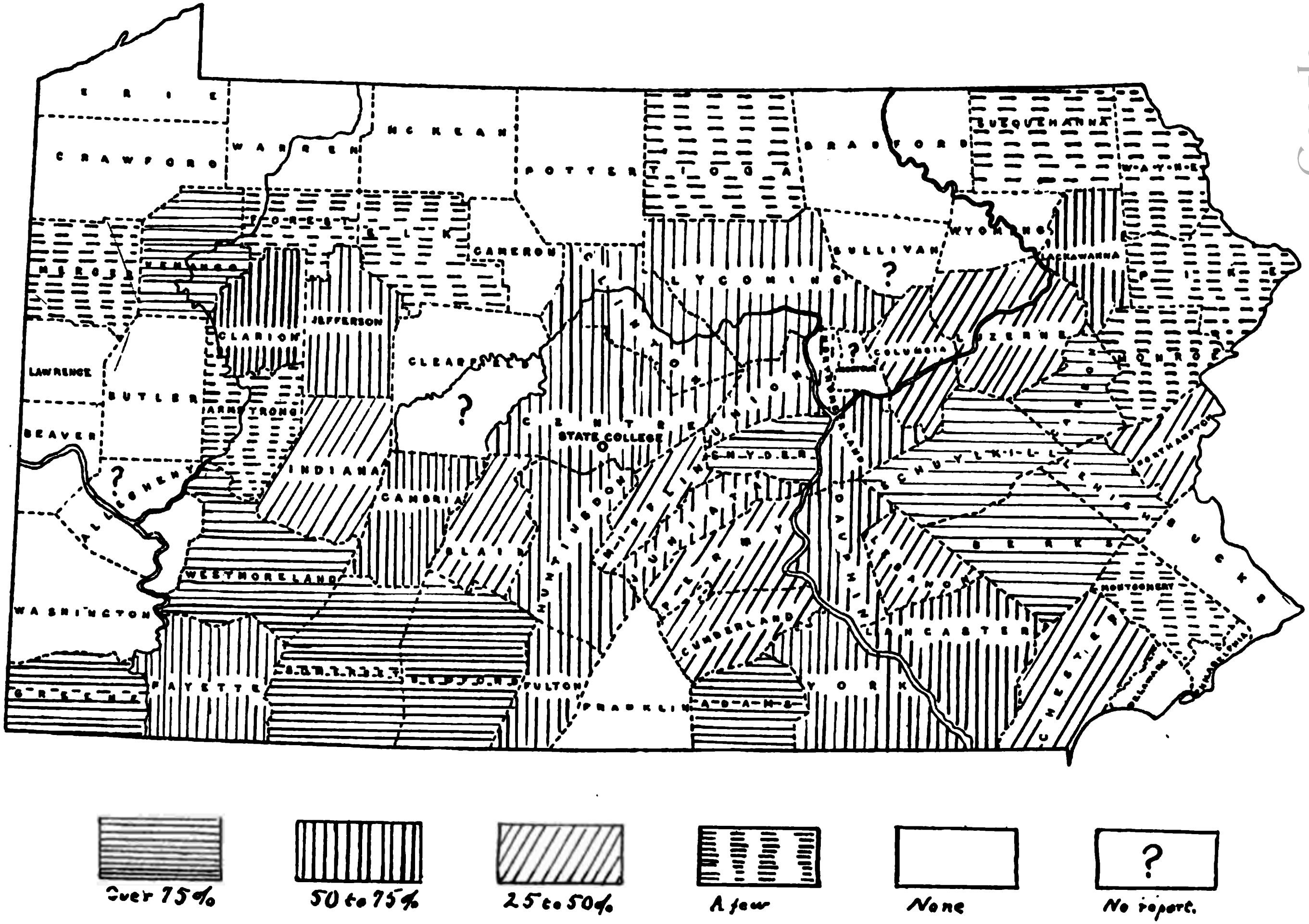
### *Soils Upon Which Lime is Used.*

The inquiry as to the nature of the lands in each locality giving the best results from the application of lime, called forth a number of general statements to which all agreed:

All soils, when rich in humus, whether new land or old soils long down in grass or heavily manured, respond well to liming, the lighter soils more promptly. It is used in large quantity on the "gladey" lands of Greene county and on certain low-lying black mucks in Snyder county.

With few exceptions, most excellent results are obtained on heavy clay soils, though the benefit often fails to appear if they are low-lying, wet and ill-drained; upland clays seem to give the best results. The white and bluish-white clays of Armstrong and Greene counties may be especially mentioned in this connection. In Pike county only is the result on light soil—gravels or sands—reported superior to that on clay.

"Limestone" land, which is usually clayey in nature, is commonly reported as benefitted by liming, but reports from Bedford county place the results on limestone soil with those on sand, and reports from Lehigh county say that these soils respond least to liming, particularly when the stone lies near the surface. Some limestones


ERIE
CRAWFORD
WARREN
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
MERCER
VENANGO
FOREST
ELK
CAMERON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
PIKE
LAWRENCE
BUTLER
CLARION
JEFFERSON
CLEARFIELD
COLUMBIA
LUZERNE
MONROE
BEAVER
ARMSTRONG
INDIANA
CENTRE
STATE COLLEGE
SNYDER
SCHUYLKILL
NORTHAMPTON
LEHIGH
ALLEGHENY
CAMBRIA
BLAIR
HUNTINGDON
MIFFLIN
JUNIATA
PERRY
DAUPHIN
LEBANON
BERKS
BUCKS
MONTGOMERY
WESTMORELAND
WASHINGTON
GREENE
FAYETTE
SOMERSET
BEDFORD
FULTON
FRANKLIN
ADAMS
CUMBERLAND
YORK
LANCASTER
CHESTER
DELAWARE
PHILADELPHIA
?
Over 75%
50 to 75%
25 to 50%
A few
None
?
No report.

leave a sand, instead of a clay; whether it is so in these cases has not been ascertained.

Sandy soils and bottom lands, except when richly supplied with humus, are usually reported to respond least to liming, but beneficial results are reported from Forest county from applications to soils that had lost their surface layers by flood. Report from Huntingdon county mentions a *heavy* sandy soil in a creek bottom, benefitted by liming, and in Lancaster county, with its broad belt of limestone clay land, the sandy soils are reported to respond best to the treatment.

Distinctly gravelly soils are commonly reported as responding well to liming, sometimes loam better than clay; but certain gravelly soils of Columbia, Indiana and Schuylkill show little benefit. Burning out of humus by heavy liming is noted from Cambria.

Certain soils received special mention in the several counties, and the facts concerning these are given below by counties:

Adams.—Ironstone soils especially benefitted; *blue* shales distinctly injured, *red* shales not.

Armstrong.—Excellent result on spouty clay, impregnated with ferrous sulfate, lying below coal outcrop.

Bedford.—Excellent results on upland slate and red shale soils.

Blair.—Much less effect on red shale than on limestone land.

Carbon.—Red shale ridge requires liming for clover.

Centre.—Light upland soils on spurs of Alleghenies respond liberally to its use for grass.

Clarion.—Light upland sandy soil—chestnut land,—and clay, respond best.

Clinton.—Best results on red shale.

Cumberland.—Most beneficial on black slate.

Dauphin.—Flint, red shale and yellow slate soils respond well.

Elk.—Good on clay below coal outcrop, which yields an acid soil.

Franklin and Fulton.—Slate benefitted by judicious applications, often showing best result.

Huntingdon.—Slate lands do well, but can not bear heavy liming.

Indiana.—Slate land stands next to clay in benefit received.

Juniata.—Has little but quick results on shale, least on land underlaid with iron.

Lancaster.—Upland slate shows good results.

Lycoming.—Best results on red and gray shales.

Northampton.—Quite good on gravel and slate lands when new.

Schuylkill.—Best on red loam.

Somerset.—Best on red soils.

Tioga.—Better on red shale than on sand.

Union.—Slates respond least.

Venango.—Dry loam and sands respond well.

Washington.—On red shale there are no good results.

These statements tend to show that slate and shale lands commonly respond well to liming, though with some sharp exceptions, which are, probably, due to the difference in the extent to which the rocks forming the soils have broken down, some slates in particular breaking down very slowly and imperfectly.

In response to questions concerning the effect of liming upon the qualities of the soil, it is almost without exception answered that the heavy soils are made lighter, more porous and more easily tilled, and that they regulate the moisture supply more perfectly, so that crops growing upon them suffer less in extremely wet or extremely dry seasons than they did upon the same soil before liming. Of the lighter soils (gravels, shales and slates), it is said that they respond quickly to small applications and are made more compact and better able to retain moisture, but that with large applications they burn out or lose their humus to too great an extent.

*Tendency Toward Increased Use of Lime.*

Irrespective of the methods of its use, the replies indicate that there is a very general tendency to return to a judicious use of liming for special purposes. Of eighty-four correspondents making reply upon this point, one-half state that its use is again on the increase in their respective localities, and only seven distinctly affirm that in their neighborhoods its use is decreasing.

Pennsylvania practice as to the methods of its use, shows wide divergences.

*Crops Limed.*

Considering first the nature of the crop to which it is applied: In most counties it is reported as being applied to ground preparing for corn, either before or after plowing; but in Blair, Bucks, Centre, Cameron, Crawford, Fayette, Forest, Pike, Susquehanna, Tioga, Venango, Washington, Wyoming and in certain sections of Cambria, Franklin, Huntingdon, Luzerne, Monroe, Northampton and Schuylkill, is it either never so applied or with less frequency than upon grass or cereals. The prevailing custom is to plow the sod under, most often during the fall and winter, and apply the lime, after first harrowing and rolling, which operations are then repeated to secure its perfect admixture with the surface soil. In Adams, Armstrong, Bedford, Blair, Clinton, Dauphin, Lawrence, Northumberland, Tioga, Union and in some sections of Jefferson, Lebanon, Lehigh, Snyder and Somerset counties, the lime is more commonly applied to the sod before plowing, during the summer if the plowing is to be done in the fall, or during the later fall and winter, if the plowing is deferred until springtime. Many of the correspondents remark that where lime is plowed under with the sod, especial care is taken to have the plowing shallow.

The occasional use of lime upon wheat is reported from nearly all localities, specific statements concerning it being absent only from reports of correspondents living in Berks, Clinton, Dauphin, Delaware, Lackawanna, Lawrence, Lehigh, Susquehanna, Washington and Wayne counties. Its use on rye is specially mentioned in reports from Blair, Fayette, Northampton and Pike counties, though its use on fall grains in general is reported in other localities. It is applied to oats, especially when sown with grass for seeding down, in Cambria, Fayette, Luzerne, Somerset, Susquehanna, Tioga and Wayne counties. When these cereals follow a sod, the application is made either before or after plowing, but when wheat or rye follows oats, the lime is not applied until the oats stubble has been plowed and harrowed.

Very commonly, the application to fall grains and to oats is for the benefit of the following crops of grass and clover. Later applications are not uncommonly made for the latter crops. In one instance, a light top-dressing on fall wheat some little time after seeding is mentioned; more frequently, the application is made after the removal of the grain. Reports from Blair, Bucks, Northampton and Snyder counties state that lime is frequently applied as a top-dressing to wheat stubble; in Centre, it is reported, clover is top-dressed by some; while its application in like manner to meadows and mowing lands is reported from Cameron, Clinton, Franklin, Indiana, Lackawanna, Lehigh, Mercer, Northampton and Washington counties.

Buckwheat land is limed before sowing in Lycoming and Monroe counties.

In Dauphin county, it is stated, lime is frequently used in preparing land for potatoes. It is applied as a top-dressing, with a heavy dressing of manure, upon the plowed ground and is then thoroughly worked into the surface by use of a spring-tooth harrow.

*Frequency of Liming.*

The replies as to frequency of application can not be readily presented in compact form. In Bedford, Blair, Cumberland, Elk, Franklin, Fulton, Lebanon, Snyder and Westmoreland the applications are not usually made more frequently than once in ten, fifteen or even twenty years. In other districts using lime, it is stated that there is a very distinct tendency to make more frequent and lighter applications, light dressings every three to five years being cited in some localities, the lighter and more frequent dressings being made to light, open soils. The local cost of liming also influences the practice in this respect quite materially.

*Amount of Lime Applied.*

The quantities applied vary from 8 to 300 bushels of unslaked lime per acre, an enormous variation, though these extremes are rare.

the lowest extreme being mentioned as occasional in Crawford and Warren counties, where lime is very costly and very infrequently used; the higher, in Greene and Fayette, where lime and coal are both abundant; even in these localities the application of such large quantities is rare. In most counties the quantities now used range from 50 to 100 bushels. The following tabulation shows where the exceptions to this rule most frequently occur:

| Counties reporting the use of 25 bus. or less. | Counties reporting the use of no more than 50 bus. | Counties reporting the use of over 100 to 200 bus. | Counties reporting the use of over 200 bus. |
|---|---|---|---|
| Adams, | Adams, | Armstrong, | Clarion, |
| Bedford, | Bucks, | Bedford, | Fayette, |
| Chester, | Cambria, | Cameron, | Greene, |
| Crawford, | Carbon, | Fayette, | Venango, |
| Dauphin, | Chester, | Fulton, | Westmoreland. |
| Luzerne, | Elk, | Huntingdon, | |
| Lycoming, | Forest, | Jefferson, | |
| Monroe, | Lackawanna, | Perry (Northern part), | |
| Montgomery, | Lebanon, | Snyder, | |
| Tioga, | Luzerne, | Somerset. | |
| Warren. | Lycoming, | | |
| | Perry (Eastern part), | | |
| | Susquehanna, | | |
| | Tioga. | | |

*Manner of Application.*

It was formerly the common practice to draw the fresh lime, at any convenient season when the soil was in condition to be least injured by trampling, upon the field, and distribute it in small heaps of a few bushels measure; it was then allowed to stand, often for a long time, until the convenience of the farmer allowed him to spread it. The merits claimed for this system were that it allowed the greatest latitude of choice for times of hauling and spreading, reduced injury from trampling of the soil and resulted in complete slaking before spreading and dispensed with any necessity for reloading the lime, which is necessary when purchased lime is slaked in large heaps. Notwithstanding these claims, the practice has given way to the better, but less convenient method, of spreading as hauled or of slaking in large heaps, reloading and spreading. The practice still remains, however, in some widely distributed districts, being reported as the usual mode in Armstrong, Bucks, Carbon, Columbia, Cumberland, Dauphin, Elk, Forest, Franklin, Lackawanna, Lehigh, Lycoming, Mercer, Snyder and Union, and in some parts of Adams, Berks, Centre, Juniata, Mifflin, Somerset, Westmoreland and York. But even in these districts it is stated that great care is taken to spread the lime after the first rain or as soon as it is slaked, instead of allowing it to stand indefinitely, as was the too frequent practice in former years.

The spreading is commonly made on a quiet day, from wagon or heap, by means of a shovel. It is often said to be impossible to evenly distribute any amount less than eighty bushels by this method, but the great number of instances in which fifty bushels or less are applied and the very infrequent use of special machinery for spreading, indicates that the inconvenience is easily overcome. The use of special lime spreaders is not mentioned by any correspondent and is quite uncommon. Those who have the modern manure spreaders find them excellent for an even distribution of lime. Correspondents from Crawford and Fulton counties state that lime is frequently applied in those localities by means of the grain drill; where the lime has been well screened, this method of applying small dressings strongly commends itself.

## II. THE LIMESTONES OF PENNSYLVANIA.

There are only three materials that are largely used as sources of lime: Sea shells of various sorts, limestone and, in England, chalk, which is really a very loose-grained, slightly coherent limestone; a fourth material, rarely employed, is coral rock.

### NATURE OF LIME.

The chief constituent of all these materials is calcium carbonate, more commonly spoken of as "carbonate of lime." This substance, when heated to a rather high temperature, gives off carbonic acid gas (carbon dioxid), and there remains lime (calcium oxid), often called "fresh burned," or "caustic" lime, to distinguish it more certainly. The lime remains for some time in lump form, in which form it is called "stone lime." If, however, water is poured or sprinkled upon it, or if it be immersed in water, it breaks down into a fine powder or into a paste or thin fluid, according to the proportion of water used; this process is called "slaking," and really consists in a chemical union of water and the calcium oxid, whereby much heat is liberated; the substances swell and sometimes become hot enough to bubble violently and liberate steam, and there is formed a new compound known as "slaked lime" (calcium hydrate). If stone lime be exposed to the air, it slowly takes up moisture therefrom and falls into powder, containing much calcium hydrate, though the operation proceeds so slowly that the heat liberated passes off gradually and never becomes intense. The calcium hydrate is quite soluble in water, and the lime water so often prescribed by the physician is nothing but a solution of calcium hydrate. Any one who has used lime water has noted that the clear liquid presently forms a white film upon its surface and a white deposit on the sides and bottom of the bottle containing it; this film and deposit are composed of carbonate of lime, for the hydrate unites very readily with the carbonic acid present in the air, thus returning to the state of chemical combination in which it existed before being subjected to "burning." A similar change occurs in slaked lime exposed, in the form of powder or paste, to the action of the air, and in "air-slaked" lime—that is, in stone-lime slaked slowly by absorption of moisture from the air—there is always quite a large amount of carbonate of lime. Some of these changes will be considered more fully in later paragraphs.

The use of oyster-shell lime is confined to a few sea-coast localities. Inland districts must rely upon the extensive deposits of limestone found in many parts of our country. It will conduce to a better understanding of some questions frequently asked concerning the agricultural uses of lime, if the history and nature of limestone be somewhat carefully considered.

## GEOLOGY OF LIMESTONE FORMATION.

When the globe was first cooled down, the lime combined chiefly, with other bases, in the form of silicates, such as feldspar, amphibole or pyroxene. It is one of the most abundant basic materials of the globe, aluminum and iron alone surpassing it. Prof. F. W. Clarke,[*] Chief Chemist of the U. S. Geological Survey, estimates that calcium (the metal of which lime is the oxygen compound and which constitutes 71.4 per cent. of lime) makes up 3.77 per cent. of the crust of the earth, taken to a depth of ten miles, 74.5 per cent. of the crust being made of oxygen and silicon. The primitive cystalline rocks of which the crust is supposed to have been at first exclusively formed, contain from 1 to 15 per cent. of lime.

### *Lime Liberated from Rocks.*

These rocks, however, under the action of atmospheric agencies, and especially of carbonic acid and water, gradually weathered or decomposed; as a result of the weathering, the lime was changed from a silicate into the carbonate or acid carbonate, sulfate and nitrate, and these, in turn, were dissoved by the rain and carried off to the ocean. T. Mellard Reade[†] estimates that at the present time the rainfall annually removes from the average square mile of the earth's surface the following quantities of the more common mineral constituents:

| | Tons. |
|---|---|
| Calcium carbonate, | 50 |
| Calcium sulfate, | 20 |
| Silica, | 7 |

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[*] Bulletin, Philosophical Society of Washington, 2, 142; Wiley, Agricultural Analysis, I, 22.
[†] *Cf.* Merrill, Rocks., p. 194.

| | Tons. |
|---|---|
| Magnesium carbonate, | 4 |
| Iron oxid, | 1 |
| Common salt, | 8 |
| Alkaline carbonates and sulphates, | 6 |
| | 96 |

*Lime in Sea Water.*

The composition of the sea water shows quite a different proportion among its several constituents, as illustrated by an analysis by Thorpe and Morton* of the waters of the Irish Sea in the summer of 1870:

| One thousand parts of the sea water contain— | Parts. |
|---|---|
| Sodium chlorid (common salt), | 26.43918 |
| Potassium chlorid, | 0.74619 |
| Magnesium chlorid, | 3.15083 |
| Magnesium bromid, | 0.07052 |
| Magnesium sulfate, | 2.06608 |
| Magnesium carbonate, | Traces. |
| Magnesium nitrate, | 0.00207 |
| Calcium sulfate, | 1.33158 |
| Calcium carbonate, | 0.04754 |
| Lithium chlorid, | Traces. |
| Ammonium chlorid, | 0.00044 |
| Ferrous carbonate, | 0.00503 |
| Silica, | Traces. |
| | 33.85946 |

Estimating the corresponding amounts of lime (calcium oxid) in the annual loss from the earth's surface as found by Reade and in sea water, we find that of the former 37.7 per cent. is lime; of the latter, only 1.7 per cent. In other words, the proportion of lime in sea water is very much less. One cause for this would be found in the removal of lime, in one form or another, from solution. Another fact of interest is that while in the material removed from the earth's crust the carbonate of lime is 2.5 times as abundant as the sulfate; in the sea water the latter is over twenty-eight times as abundant as the carbonate. It might be inferred therefrom that the carbonate had been removed far more rapidly than the sulfate.

The foregoing analysis of sea water shows it to contain one part of carbonate of lime in 20,000 parts of water. Comey, in his *Dictionary of Solubilities* (p. 82), quotes Irvine and Young as stating that one part of the carbonate is, according to its condition and fineness, dissolved by 1,600 to 8,000 parts of sea water, whose solvent action for this substance is greater than that of pure water. It is evident that the lime is not separated or precipitated from the solution in sea water by any method known to the laboratory, and Bischof[*] states that the ocean at present contains seven times as much carbonic acid as is necessary to retain all the lime in solution, and that for its deposition upon the sea bed living organisms must, therefore, intervene.

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*Chem. Soc. Journ., 24, 506; Roscoe and Schorlemmer, Treatise, I, 257.

*Calcium Carbonate Secreted by Animals.*

As a matter of fact, it is found that the skeletons or shells of many of the lower animals living in the sea are quite largely made up of carbonate of lime; the coral polyps, foraminifera, brachiopods, crustaceans and many lamellibranchs and gasteropods may be cited as belonging to this class. Dana[†] cites some analyses by S. P. Sharpless that serve to show how largely carbonate of lime is taken up by these organisms.

| | Madrepore coral. Per cent. | Oculina coral. Per cent. | Shell of Terebratula. Per cent. | Oyster shell. Per cent. |
|---|---|---|---|---|
| Calcium carbonate, | 97.19 | 95.37 | 98.39 | 93.90 |
| Calcium phosphate, | 0.78 | 0.84 | 0.61 | 0.50 |
| Calcium sulfate, | ............... | ............... | ............... | 1.40 |
| Magnesium carbonate, | ............... | ............... | ............... | 0.30 |
| Water and organic matter, | 2.81 | 3.79 | 1.00 | 3.90 |
| | 100.78 | 100.00 | 100.00 | 100.00 |

The temperature of the deep sea is too low to allow these forms of life to flourish there. Murray, in reporting the results of the deep-sea explorations of the *Challenger Expedition*, states that the ooze from deep-sea bottoms is of a reddish color, is largely composed of iron oxid and contains little lime; if the rhizopods (foraminifera) and other minute organisms find a fitting home near the surface of the mid-ocean their skeletons are probably dissolved when, after the death of the animal, they slowly sink toward the sea bottom; to give further probability to this theory, analyses of carefully taken samples of water from the lower depths of the deep sea exhibit a larger proportion of lime than is found in the surface waters. The best known lime-secreting organisms of the present day do not live in water deeper than 100 fathoms, nor is the wave action at great depths sufficiently strong to pulverize the shells, coral, etc., whose debris deposited as ocean slime, later becomes the solid bed of limestone. As somewhat illustrating these differences there may be cited certain analyses by Storer[‡] of two series of deposits from the sea bottom, (1) a series taken by Lieut. Berryman, U. S. N., off the coast of Nova Scotia, near the northern edges of the Gulf Stream, at depths of 1,100 to 1,300 fathoms; (2) a series taken by Lieut. Brooke, U. S. N., in the Pacific ocean, between California and China, in the track of the Equatorial and North Pacific currents, at depths of 900 to 3,000 fathoms, chiefly at the greater depths:

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[*] Cited by Reid: Portland Cement, etc., 1877, p. 50.

[†] Manual of Geology, p. 211.

[‡] Bulletin of the Bussey Institution, Harvard University, II, 21-3.

| | (1) | (2) |
|---|---|---|
| Silica and sand, | 40.5 to 51.1 | 60.6 to 74.8 |
| Alumina and ferric oxid, | 7.7 to 8.8 | 12.4 to 19.0 |
| Lime, | 17.1 to 18.8 | 1.4 to 2.7 |
| Magnesia, | 1.7 to 1.8 | 1.6 to 3.3 |
| Phosphoric acid, | 0.2 to 0.3 | 0.3 to 2.0 |
| Potash, | 2.1 to 5.8 | 2.1 to 4.1 |

If further evidence is necessary, it is furnished by an examination of the limestone rocks themselves. In many, the shell forms and coral structure are distinctly preserved; under the microscope, the oölitic limestone plainly reveals its animal origin, while the chalk cliffs of southern England are built up almost wholly of the skeletons of foraminifera, over a million of which are requisite to make one cubic inch of chalk.[*]

*Decomposition of Calcium Sulfate.*

One other fact should be mentioned in accounting for the tremendous deposits of limestone that mark the later history of the earth's crust, namely, that the lime carried to the sea in the form of carbonate is not the only supply from which these great formations were built, but the sulfate also contributed in an important measure. While the loss from the earth's surface in percolating rain, estimated by Reade, and the analysis of sea water by Thorpe and Morton, do not warrant too close comparison, it is clear that, as compared with the common salt, the sea water contains much less sulfate of lime than the waters of percolation. While this compound, as it occurs in gypsum or land plaster, is considered to be one of the less readily destructible compounds known to man, it is well known to plant chemists, that the crops can take it up and that the plant stem, at later stages of growth, is sometimes free from sulfates, under such conditions that the destruction of these salts within the plant to furnish sulfur for the building of albuminoids is believed to be established. The decomposition of calcium sulfates to form the sulfid through the activity of lower plant life seems also to be well established, and Olivier and Etard[†] claim that certain algae may even set sulfur itself free from sulfate of lime. Bernard[‡] has noted the liberation of sulfuretted hydrogen as a consequence of the reduction of sulfate of lime in springs and in sea water when abundance of organic matter was present. Buchanan[*] has shown that the mud of the sea bottom, which is being continually passed through the alimentary tracts of marine animals, has the sulfate of lime it contains reduced under this treatment to calcium sulfid, the same form that results from the reducing action of water plants to which reference has just been made.

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[*] Stockbridge, Rocks and Soils, 1895, pp. 35-6.

[†] Cited by Bernard: Le Calcaire, 1893, p. 245.

[‡] *Loc. cit.*

The formation of calcium sulfid being established, it remains to be noted that this substance when dissolved or suspended in water containing carbonic acid, is quickly decomposed with the liberation of sulfuretted hydrogen and the formation of carbonate of lime.[†] Dehérain[‡] states that sulfids formed in soil rich in humus very quickly undergo similar conversion into the corresponding carbonates.

From these facts it is clear that the great limestone formations have drawn for their material not simply upon the lime brought to the sea in the form of carbonate, but also indirectly upon that brought down in the form of sulfate.

### *Quantities of Lime in Pennsylvania Limestone Rocks.*

The writer estimates, assuming the limestone to have a specific gravity of 2.7 and that it contains roughly an average of 80 per cent. of carbonate of lime, that the Lower Silurian lime formations of Central Pennsylvania, which are about 5,000 feet, or nearly a mile, in thickness, contain upwards of 94,000,000 of tons of calcium carbonate for each square mile of these strata. While the mind can not conceive of such enormous quantities, they serve to impress upon the imagination the wonders of these great geologic changes.

### *Later Changes in Limestones.*

These beds, after being raised above the surface of the ocean by some of those frequent changes of level that have marked the history of the earth's crust, have not only become comparatively dry and solidified but, in consequence of pressure, heat and other changes have often assumed a crystalline character such as is exhibited in the pure limestones yielding fine marble. Percolation of surface waters through beds of limestone have dissolved[§] much of the carbonate of lime in many localities and strata, leaving the more easily attacked rocks greatly honey-combed; indeed, the great caverns of the limestone regions, such as the Mammoth Cave, of Kentucky,

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[*] Proc. Roy. Soc., Edinburgh, 1890-1, cited by Merrill, Rocks, p. 204.

[†] Malaguti, Lecons de chimie, II, p. 150.

[‡] Traité de Chimie agricole, p. 547.

[§] Note.—The authorities cited by Comey (Dictionary of Solubilities, p. 82) indicate that one part of calcium carbonate requires, according to its condition of subdivision, hardness, etc., from 10,601 to 100,000 parts of water for its solution. If, however, the water be saturated with carbonic acid, as soil water often is in part, only 800 to 3,149 parts are required to dissolve one part of the carbonate, the acid calcium carbonate being thereby formed.

Luray Caverns of Virginia, and the interesting Penn's Cave, of Central Pennsylvania, have been formed by this dissolving, percolating process.

### IMPURITIES IN LIMESTONES.

The history of the limestone formations renders it also apparent that great quantities of material other than calcium carbonate must have entered into their composition. The sedimentary limestones in which crystallization does not appear, are colored, not white, and often contain large quantities of *sand*, *clay*, whose deposition upon the shallow sea bottoms from the down-wash of neighboring uplands is readily understood, and of *iron pyrites* (sulfid of iron). When the limestone crystallized, the same conditions brought about changes in the accompanying impurities, and Merrill* mentions, as accessory to crystalline limestone and resulting from such changes or originally present, minerals of the mica, amphibole and pyroxene groups, and frequently sphene, tourmaline, garnets, vesuvianite, apatite, pyrite, graphite, etc.

Owing to their animal origin, the presence of small quantities of *carbonaceous matter* in limestone is not surprising. The dolomitic limestones of Cook county, Ill., contain so much material of a bituminous nature that, when struck by hammer, a distinct odor like that of petroleum is evolved.

For the same reason the presence of *phosphorus* is to be anticipated and, according to Merrill,† the quantity of phosphoric acid in limestone often exceeds that found in either the older siliceous rocks or in other rocks of more modern formation. He gives the following ranges for the percentage of phosphoric acid in some of these rocks:

| | Per cent. |
|---|---|
| Granite, | 0.07— 0.25 |
| Diorite, | 0.18— 1.06 |
| Basalt, | 0.03— 1.18 |
| Limestone, | 0.06—10.00 |
| Shale, | 0.02— 0.25 |
| Sandstone, | 0.00— 0.10 |

The higher percentage given for limestone is one that is very rarely obtained.

The *color* of limestone, marble and travertine (onyx marble) may be white, yellow, brown, red, green, gray, blue or even black. These colorations are sometimes due to carbonaceous matters, sometimes to metallic oxids, iron oxids especially, and sometimes to both. In the white and green varieties, according to investigations of Merrill,‡ the iron exists as carbonate, in the yellow, brown and red forms, as a more or less hydrated sesquioxid of iron. Bernard[*] attributes the blue colors of limestone chiefly to organic matters, having found from 1.25 to 2.38 per cent. of such matters in the blue oölithic limestone taken from the bed of the river Marne, in France. The same investigator found, in a clear yellow limestone, in addition to some suspended yellow sesquioxid of iron, to which its color was due, a large quantity of ferrous iron, doubtless present in the form of carbonate. The changes of color which some limestones experience when exposed to the weather are chiefly due to the destruction of the organic matter and to oxidation of the ferrous carbonate and sulfids they contain.

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*Rocks, p. 162.

†*Op. cit*, p. 7-8.

‡*Op. cit*, p. 553.

The flint present in many limestones is believed to be derived chiefly from members of the sponge family, which contain considerable silica.

### MAGNESIAN LIMESTONES.

There remains for brief consideration the most striking and difficultly explicable foreign constituent of lime, magnesium carbonate, from which few limestones are entirely free, and which is often present in equal molecular proportion with calcium carbonate, forming the mineral *dolomite;* this contains 46.5 per cent. of magnesium carbonate. There are no marine organisms now in existence whose skeletons contain any such proportion of magnesium carbonate. Dana[†] cites Damour as having found 19 per cent. in corals of the genus *Millepora*, and Forchhammer as having found 6.36 per cent. in *Isis nobilis*, and 2.1 per cent. in the precious coral of the Mediterranean. A single case of magnesian fossil (*Orthocerus*) is mentioned by Dr. T. Sterry Hunt[‡] as containing 37.8 per cent.; it was found in the non-magnesian Trenton limestone at Bytown, Canada. Neither is the theory satisfactory that the calcium carbonate was dissolved out by water, leaving behind the magnesium carbonate, whose proportion was thereby increased; no known sea-bed formation of this day contains more than 4 or 5 per cent. of magnesium carbonate; in other forms than dolomite, the magnesium carbonate is more soluble than that of calcium;[§] and so large a withdrawal of material from the bed must, it is believed, result in dolomite being universally crumbled or porous; whereas, on the contrary, it is usually more compact than ordinary limestone, and contains fossils of unchanged form.

The more commonly accepted theory for the formation of limestones rich in magnesia is that the sea water has given up magnesia in exchange for lime from the rock. The known facts do not make the theory entirely satisfactory, but it is less objectionable than the others proposed.

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[*] Le Calcaire, pp. 193-4.

[†] Manual of Geology, p. 211.

[‡] *Ibid*, p. 69.

[§] Note.—Comey (Dict. Solubilities, p. 87) cites authorities to show that one part of magnesium carbonate requires for solution 5,071 to 17,600 parts of pure water, and from 28 to 8,700 parts of carbonated water. The action of sea water is not stated.

Dolomites weather, as a rule, more slowly than pure limestones, though there are exceptions to the rule; they do not give off carbonic acid with effervescence when touched with cold hydrochloric or acetic acid as pure limestones do, and their density is greater, the specific gravity of dolomites ranging from 2.8 to 2.95, while that of pure, compact limestone ranges from 2.6 to 2.8, though both are heavier than the average other rocks from which both are formed.

### LIMESTONE FORMATIONS OF PENNSYLVANIA.

It has been remarked in and earlier paragraph that this State has a great variety of rock materials. J. D. Dana (Manual of Geology, 3d ed., 1879, p. 375), describes the sequence of exposed geological formations in Pennsylvania as follows, beginning with the lowermost or oldest that has been certainly identified:

## PALAEOZOIC TIME.

### SILURIAN AGE, OR AGE OF INVERTEBRATES:

#### Lower Silurian:

PRIMORDIAL PERIOD, *Potsdam Epoch:* Sandstone and slates, 3,000 to 4,000 ft. thick.

CANADIAN PERIOD, *Calciferous Epoch:* Calcareous sandstone, 250 ft.

*Quebec and Chazy Epochs:* Magnesian limestone, with some cherty beds, 5,400 ft.

TRENTON PERIOD, *Trenton Epoch:* Limestone, with blue shale, 550 ft.

*Utica Epoch:* Bituminous shale, 400 ft.

*Cincinnati Epoch:* Blue shale and slates, with some thin gray calcareous sandstones, 1,200 ft.

#### Upper Silurian:

NIAGARA PERIOD, *Oneida Epoch:* Gray sandstone and conglomerate, 700 ft.

*Medina Epoch:* Red sandstone and shale, 1,050 ft., and white sandstone, with olive and green shales, 760 ft.; total, 1,810 ft.

*Clinton Epoch:* Shales of various colors, both argillaceous and calcareous, with some limestones, ferruginous sandstones and iron-ore beds, 2,600 ft.

*Niagara Epoch:* Not well defined.

SALINA PERIOD, *Saliferous Epoch:* Variegated marls and shales, some layers of argillaceous limestone, 1,650 ft.

LOWER HELDERBERG PERIOD: Limestone, thin-bedded, with much chert, 350 ft.; encrinal and coralline limestone, 250 ft.; total, 600 ft.

ORISKANY PERIOD, *Oriskany Epoch:* Calcareous shales and calcareous and argillaceous sandstone, 520 ft.

### DEVONIAN AGE, OR AGE OF FISHES:

CORNIFEROUS PERIOD, *Cauda-galli Epoch:* Silico-calcareous shales, 200 to 300 ft.

*Corniferous Epoch:* Massive blue limestone, 80 ft.

HAMILTON PERIOD, *Marcellus Epoch:* Black and ash-colored slate, with some argillaceous limestones, 800 ft.

*Hamilton Epoch:* Argillaceous and calcareous shales and sandstone, 1,100 ft.

*Genesee Epoch:* Black calcareous slate, 700 ft.

CHEMUNG PERIOD, *Portage Epoch:* Dark gray, flaggy sandstones, with some blue shale, 1,700 ft.

*Chemung Epoch:* Gray, red and olive shales, with gray and red sandstones, 3,200 ft.

CATSKILL PERIOD: Red sandstone and shale, with some conglomerate, 6,000 ft.

### CARBONIFEROUS AGE, OR AGE OF COAL:

SUB-CARBONIFEROUS PERIOD, *Lower Epoch:* Coarse, gray sand stones and siliceous conglomerate at the east, becoming fine sandstones and shales at the west, 2,660 ft.

*Upper Epoch:* Fine red sandstones and shales, with some limestone, 3,000 ft.

CARBONIFEROUS PERIOD, *Millstone-Grit Epoch:* Siliceous conglomerate, coarse sandstone and shale, including coal beds, 1,100 ft.

*Coal measures*, 2,000 to 3,000 ft.

The more recent explorations of the Second Geological Survey of the State add to the formations given in this list. In the first place, of the rocks of the Azoic Age, or that before the appearance of life on the globe, there is an exposed thickness of 15,000 feet cut by the Schuylkill River, made up of crystalline silicates.

At the other extreme of the geological scale, in the Mesozoic, or Reptilian Age, the Triassic and Cretaceous Periods are distinctly represented, the former by red granitic sandstone, with conglomerate, occasionally impure limestone and rarely shale, and with numerous ridges and dikes of trap rock; in Bucks county the maximum thickness of 27,500 feet is reached. The Cretaceous Period is represented by a brick-clay and gravel formation, occupying a very small area on the Delaware river, just below Trenton; it is a continuation of the formation so distinctly marked in New Jersey by beds of green-sand marl.

In many localities the thicker limestone strata are, of course, buried far below the surface; but even in such case, the deep channel of a river bed or valley often renders them accessible.

The geological map of the State shows that the Lower Silurian limestones form the surface of the land in three, more or less broken belts stretching from the eastern border, in a southwesterly direction, across the southeastern portion of the State. The first belt appears in Bucks, Montgomery, Chester, Lancaster, York and Adams counties; the second in Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland and Franklin, while the third, much broken, appears in the numerous parallel curved valleys crossing the southern central portion of the State, in Fulton, Bedford, Perry, Mifflin, Juniata, Blair, Centre, Union, Clinton and Lycoming counties.

The Lower Helderberg limestone formation appears exposed on the mountain sides in very narrow and thin belts, in every county south of Pike, Luzerne, Sullivan and Tioga that lies between the main range of the Allegheny mountains, on the west, and, on the east, the depression crossing the State from Easton to Chambersburg.

In many parts of western Pennsylvania, limestones of the coal measures are available.

Replies from correspondents show that in the northern counties lime is little used, because of its having to be brought in from other localities at great cost, as in case of the small quantities reported in use in Pike, Wayne, Tioga, Cameron, Elk, Forest and Crawford counties; in the western counties south of these, except in Clearfield, for which no report was received, and Beaver, where none is used, many of the farmers are reported as burning their own lime.

Neither time nor space will permit in this paper a discussion of the various strata and localities from which limestone may be obtained in each county of the State. One interested in that question should refer to the reports issued for the county by the Second Geological Survey of Pennsylvania.

As will be made more fully evident in the later discussion of the composition of limes, some knowledge of the composition of a limestone which it is proposed to use should be had before going to any considerable expense in quarrying and burning it.

As a matter of more interest geologically than from a practical point of view, it may be stated that researches by the Kentucky Geological Survey indicate the older limestones to be, as a general rule, richer in soda, phosphoric acid and, when non-magnesian, in carbonate of lime, than are the younger or more recently formed, and correspondingly poorer in silica and insoluble silicates (clay, etc.).

*Analyses of Pennsylvania Limestones.*

It has been thought that some value might be derived from a compilation of available analyses of limestones from various localities in the State. Such a compilation, chiefly from the reports of the Second Geological Survey, has been made under the writer's direction by Mr. C. A. Browne, Jr., Assistant Chemist of the Pennsylvania State College Agricultural Experiment Station. These are presented in Appendix B.

*Variability of Limestone from Same Quarry.*

It is not probable that the analysis of any single specimen of limestone will correctly represent the entire output from a quarry. The stone varies in composition through the same stratum or bed; but especially are differences of composition observed in the stone from different strata in the same quarry. The most complete study of such variations known to the author is that made by Prof. Peter J. Lesley and Dr. Andrew S. McCreath* upon the composition of the stone of 115 beds exposed in the Walton (McCormick) quarry, opposite Harrisburg. As a typical example of the results obtained, the analyses of rock from the last five beds (Nos. 111-115) may be taken, two samples, one from each end of the sloping bed, having been analyzed in each stratum:

| Bed No. | Thickness of bed. Ft. In. | Calcium carbonate. | | Magnesium carbonate. | | Insoluble matter. | |
|---|---|---|---|---|---|---|---|
| | | Lower sample. | Upper sample. | Lower sample. | Upper sample. | Lower sample. | Upper sample. |
| 111, .................. | 5—6 | 94.5 | 88.4 | 2.7 | 8.3 | 1.9 | 2.6 |
| 112, .................. | 1—7 | 54.4 | 54.4 | 35.2 | 36.2 | 8.4 | 7.7 |
| 113, .................. | 5—6 | 98.1 | 76.2 | 0.9 | 3.7 | 1.0 | 18.2 |
| 114, .................. | 5—6 | 64.6 | 55.4 | 26.2 | 33.8 | 8.5 | 9.7 |
| 115, .................. | 14—6 | 95.1 | 97.7 | 1.9 | 0.9 | 1.7 | 1.4 |

Among the beds retaining their individuality of composition throughout their entire exposure, were some of not more than eight inches thickness.

*Range of Composition.*

An examination of the compiled analyses shows that the several important constituents range in proportion from a faint trace to the following maximum percentages:

| | Per cent. |
|---|---|
| Insoluble, .............................. | 80.95 |
| Iron and aluminum oxids, .................. | 10.07 |

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*Report of the Second Geological Survey of Pennsylvania, Vol. MM, pp. 311-361, and Final Report, Vol. I, pp. 327-336.

| | Per cent. |
|---|---|
| Calcium carbonate, | 99.30 |
| Magnesium carbonate, | 46.00 |
| Sulfuric acid, | 6.08 |
| Phosphoric acid, | 1.82 |

There were very few true dolomites among these samples. Some of them contained so much impurities that they can not properly be called limestones, but should be termed calcareous shales, sandstones, etc. The quantity of phosphoric acid will scarcely average as high as 0.1 per cent.

## III. LIMES AND LIME BURNING.

Limestone and other forms of calcium carbonate, it has been remarked in an earlier paragraph, lose carbonic acid when heated and are thereby converted into calcium oxid, or lime. Upon complete burning, 100 pounds of pure calcium carbonate yield 56 pounds of lime.

### TEMPERATURE OF LIME-BURNING.

To effect this decomposition a high temperature is required. Thorpe and Grove, in their treatise on "Manufacturing Chemistry," state that the disengagement of carbonic acid first begins at a temperature of 752 degrees Fahr. (400 degrees C.), a temperature somewhat above the highest employed in a baker's oven, but that this disengagement does not go on fully until a temperature of 1,494 degrees Fahr. (812 degrees C.) is reached.

The conclusions of other observers differ somewhat from those of Thorpe and Grove. Thus, Hans A. Frasch[*] states that the normal temperature of burning is 850 degrees C. (1,562 degrees Fahr.); that pure calcium carbonate heated for four hours at 615 degrees to 675 degrees C. (1,139 degrees to 1,247 degrees Fahr.), lost none of its carbonic acid; for three hours at 860 degrees to 880 degrees C. (1,580 degrees to 1,616 degrees Fahr.), lost less than 10 per cent., but heated for two hours at 850 degrees C. it lost all its carbonic acid. Heated very intensely the pure carbonate fuses and the escape of the carbonic acid is almost entirely prevented.

As to the effect of heating upon the other constituents of the limestone, whatever the intermediate reactions may be, the final outcome is that the carbonates of magnesia and iron give off their carbonic acid, and remain as magnesia and ferric oxid; iron pyrites loses its sulfur and is likewise oxidized; all organic matter is driven off or destroyed, and water, which is present as "quarry water" to the extent of 0.3 to 5 per cent., and often also in some small quantity as water of combination with sulfate of lime and hydrated iron and aluminum oxids is expelled. Sand and other insoluble impurities are assumed, if the stone be carefully heated, to undergo little or no change. Calcium sulfate and calcium phosphate, if the phosphoric acid present is really combined with calcium rather than iron or aluminum, are supposed to undergo no change in their final state of combination, though no careful investigation of this point is known to the writer.

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[*] The Mineral Industry, Vol. VII (1899), p. 483 *seq.*

### LOSSES DURING BURNING.

In the following table a simple example of the loss which the several constituents of a limestone undergo in a perfect burning is given:

| Constituents. | In 100 lbs. of the original stone. Lbs. | Loss. Lbs. | Residual lime. Lbs. | Percentage composition of the fresh-burned lime. |
|---|---|---|---|---|
| Water (both quarry water and water of combination) and organic matter, | 3.00 | 3.00 | ........ | ........ |
| Sand, clay, phosphate of lime, anhydrous sulfate of lime, and oxids of iron and aluminum, | 7.00 | ........ | 7.00 | †13.75 |
| Calcium carbonate, | 70.00 | 30.80 | 39.20 | 70.07 |
| Magnesium carbonate, | 19.00 | 9.95 | 9.05 | 16.18 |
| Ferrous carbonate, | 1.00 | .38 | *.69 | ........ |
| | 100 00 | 44.13 | 55.94 | 100.00 |

*In its conversion to ferric oxid, 1 part of ferrous carbonate takes up .07 parts of oxygen from the air.

†Including the ferric oxid from ferrous carbonate.

That is, there remains none of the water or organic matter, all the sand, clay, etc., besides ferric oxid equivalent to 69 per cent. of the weight of the ferrous carbonate in the limestone, magnesia equivalent to 47.63 per cent. of the magnesium carbonate and lime equivalent to 56 per cent. of the calcium carbonate. These factors may be applied in estimating the yield of lime from limestone whose composition is known.

### YIELD OF LIME.

Several questions concerning the yield of lime are frequently asked. 1. How much stone is required to yield a bushel of fresh-burned lime? Taking a stone of the composition first given, and the standard weight of 72 lbs. for the bushel weight of the lime, the answer would be $\frac{100}{56}$

of the lime (72 lbs.), or 128.6 lbs. With poorer limes, the weight required is less. 2. How much lime will a perch of limestone yield, assuming proper burning? This, evidently, depends upon two things: first, the density of the stone and its freedom from pores, which determine its weight; second, its composition, by which the loss during burning is determined. For illustration, take the two very simple cases of marble and of dolomite, which are each supposed to contain, as the only material other than carbonate, 2 per cent. of water and organic matter. Fair average specific gravities for these substances are, for marble, 2.72; for dolomite, 2.9; so that the weight of a cubic foot of water being 62.5 pounds, the weight of a cubic foot of these rocks would be 170 and 180.25 pounds, respectively; and a perch of the solid material (24¾ cu. ft.) would weigh, for the marble, 4,207.5 lbs.; for the dolomite, 4,234.67 lbs. The residue from burning 100 lbs. of the marble would be 56 per cent. of 98 lbs. (the amount of carbonate of lime present), or 54.9 lbs., so that one perch would yield 2,309.9 lbs., or 32⅝ standard bushels of 72 lbs. each. Each 100 lbs. of the dolomite would yield 51.8 per cent. of 98 lbs., or 50.8 lbs. of lime, (lime and magnesia, more correctly), equivalent to a yield of 2,151 lbs., or 29.9 standard bushels, for each perch of the solid stone.

## METHODS OF BURNING.

Lime is burned in Pennsylvania both in "heaps," similar to those for preparing wood-charcoal, and in kilns of various types. Either wood or coal, or in some cases, both, are used as the fuel. The coal used is usually bituminous, of which the "slack," or cheaper grades are often employed.

### *Burning in Heaps.*

Burning in the "heap" is practiced in Centre county about as follows: A convenient oblong piece of ground is cleared, and leveled if need be, to secure a fit platform. Upon this is laid a layer or two of good cord-wood, better well seasoned. Between the chinks in the cord-wood, shavings, straw or other light kindling is placed. The stone having been reduced to the size of a double fist, sometimes not so small, is laid upon the cord-wood, care being taken to leave chinks between the stones just as between the bricks in a brick kiln; it is preferred that this layer of stone should not exceed six to ten inches in thickness. In some cases, temporary wooden flues, filled with straw, are erected, either one at the center or, if the heap is oblong, one near each end, and the stone and coal are built up around them; thus, when they are burned out, a chimney draught or two is secured, which may be damped by pieces of stone or sod. Upon this layer of stone is spread a layer of coal, and upon that a thicker layer of stone (12 inches), and so on, coal and stone alternating until the oblong heap is topped with smaller stone. The proportion of coal is diminished in the upper layers, the effort being to distribute one-half of the total coal employed in the two lower layers, so as to secure the highest economy possible in this use of the fuel. Fire is then kindled in the straw or shavings; when the flames have communicated themselves to the cord-wood and lowermost layer of coal, and tongues of flame shoot out from the crevices in the sides of the heap, earth, previously loosed by a few turns of the plow about the heap, is rapidly spread over the entire heap, thus damping the draughts and retarding the combustion. Fig. 1 represents crudely this arrangement of the materials in the heap. Steam and smoke slowly escape during the first hours, but later the entire heap, including the outer covering of earth, is heated to a dull red glow. The burning goes on slowly for several days, the interior often being hot for several weeks. When the lower portion of the heap has reached an advanced state of calcination, a portion of the outer layer of lime sometimes slips down; if so, a fresh covering of earth must be promptly applied at the exposed point; otherwise, it will serve as a vent for the heat, and the top and other sides will fail of proper calcination.

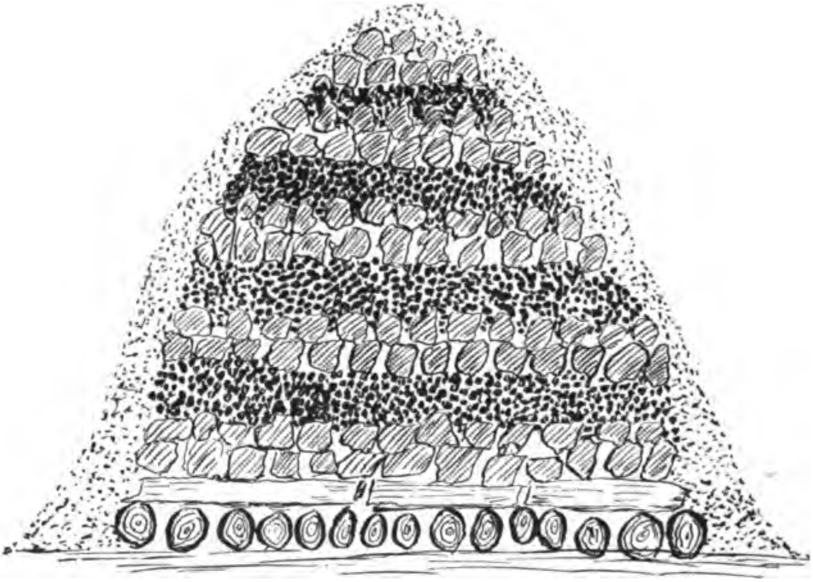

Fig. 1.

In other localities the heap is covered with compact earth or sod before the fire is kindled, a few openings being left at the top, whereby the steam and smoke may escape; these openings are stopped as soon as the smoke has disappeared. Low* states that in England a compact wall is carefully built around the lower portion of the heap, with proper draught holes, and that the top is covered with turf or mud. "This," he says, "is an expensive method of burning, from the large quantity of fuel required; but from the more slow and gradual combustion, the lime is reckoned superior to that produced by other means." The quantity of fuel used in Centre county is roughtly one ton of coal for each 100 bushels of lime, though a heap of 3,000 bushels is sometimes satisfactorily burned with twenty tons of coal; that is, the ratio of coal to lime ranges from 1:3.5 to 1:5, or, estimating on the basis of compact limestone, yielding about thirty bushels of lime to the perch, one ton of coal would burn from three and one-third to five perches.

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*Landed Property and Economy of Estates, p. 494.

Frasch* expresses the fuel requirement in other terms, viz: as 1.25 volumes of coal slack for each six volumes of stone.

*Kiln Burning.*

Of kilns there is a great variety in form and construction, but they may be grouped as belonging to one of three types:

A. Intermittent kilns, which require the complete calcination and removal of one charge before another can be introduced.

B. Perpetual kilns, from which the earlier calcined portions can be removed and fresh charges introduced while the burning is in progress. Of these there are two kinds:

a. Ordinary draw-kilns, in which the fuel and stone are introduced in alternate layers.

b. Flame-kilns, into which the stone is introduced, unmixed with fuel.

The *intermittent kiln* is not so frequently used as the draw-and flame-kilns. It is sometimes employed where quite small quantities of lime are to be prepared with the use of wood as fuel. In such kilns, a dome of large pieces of limestone is built within the kiln, the inner walls of the kiln forming the abutment upon which it rests. During the forming of the dome, the stone is supported upon false work. Upon this dome the smaller stone is placed until the kiln has filled. Well-seasoned short-length wood is then set on end upon the grate, with which such kilns should be supplied, and kindled. The draught must be carefully regulated to ensure a gentle heat at the outstart, the fire being gradually increased during eight hours; otherwise, the quarry water in the large stone will be too suddenly converted to steam, rending them and possibly causing the arch to give way. The mass will then have settled about one-sixth and a crow-bar will work easily in it; the top of the kiln is then closed to confine the heat and complete the calcination of the upper layers, which requires ten to twelve hours more. With such kilns, the vertical distribution of heat is very uneven; hence, the kilns are made of rather large diameter and low, so that the bottom lime may not be overburnt and the top layers left "raw" or incompletely calcined.

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* The Mineral Industry, VII 1889, 483 *seq.*

Frasch* states that in such kilns from two to three volumes of hard wood are required for each volume of lime.

The *flame kiln* will be mentioned next. In this kiln the draw-arch is situated below and is independent of the fire-arch; and the latter is always provided with a grate and underlying shallow pit from which the ashes may be removed as necessary. Because of these peculiarities of construction, as well as for the purpose of securing a good draught, flame-kilns are usually given a relatively great height. Also, with the object of securing a more even firing, a single kiln usually has two or more fire arches opening into it from different sides, the fuel being delivered to an elevated platform, from which it is shovelled upon the grate as the burner thinks necessary. Many such kilns have, instead of a circular, hozizontal cross section, one of oval form, the diameters being to each other approximately as four to six. Just about the level of the fire arches, the interior of the kiln is divided by a vertical wall, the top of which is narrowed to a sharp ridge, while the thickness of the wall increases toward its base in such manner that the interior of the kiln is divided into two compartments gradually curving out toward the draw-arches. All openings into the kiln are provided with doors, permitting the regulation of the draught. It is claimed for these (1) that they keep the lime free from impurities introduced in the fuel; (2) that the stone is more evenly burned; (3) that they are more convenient in working; and (4) that they are by far the most economical in their fuel requirements. The kiln should have such capacity as to hold from 1.75 to 2 times the amount of stone required for the daily yield of lime desired; the material is subject to the heat for twenty-four to forty-eight hours, and the lime is drawn every six to eight hours as the capacity of the "thimble," or receptacle for the burnt lime in the lower portion of the kiln, may make needful. The saving in fuel, at least when wood is used, is claimed to be at least three-sevenths of that required by intermittent kilns of the same output. Various manufacturers estimate that one cord of wood will burn from 60 to 110 bushels of lime, according to the quality of the fuel and stone and the conditions of burning. Frasch estimates that in the flame-kiln thirty-six to forty pounds of hard wood is required for each cubic foot of lime produced, and that in the Hoffman type of kiln, five pounds of coal slack is sufficient for this volume of lime.

The flame-kiln is, for the production of lime of a very pure, even quality and for economy of fuel, which reaches its highest importance in large operations carried on continuously, to be preferred to any other type of kiln.

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*Loc. cit.

The ordinary *draw-kiln* is, however, far cheaper in construction, and for this reason, is commonly adopted where operations are not extensive and where the inclusion of some ashes from the intermixed fuel is not highly injurious to the use for which the lime is intended. There are many differences in the detail of construction of such kilns. The writer has seen in Somerset county, in a locality where suitable building stone for exterior walls is not readily obtainable, kilns whose outer walls and draw-arch are constructed simply of a crib-work of rough, notched logs; the interior walls were built up somewhat in the form of a peach basket, from thin sandstone found in the neighborhood, laid flat sides horizontal; between this inner shell and the crib work, clay was carefully tamped in, forming a retaining wall for the lining of the kiln. Figures 2 and 3, after Gilmore, represent cross-sections of two common forms of draw-kilns; that represented by Fig. 3 being most frequently adopted in Pennsylvania. The outer walls are commonly built of limestone, sometimes of brick; instead of being vertical, as represented in the cut, it is preferred that they should have a slight batter. Since they have a tendency to crack and spread near the top after the kiln is heated, it is best to use, to strengthen the upper walls, several sets of iron tie-rods, crossing from side to side in the space between the inner and outer walls of the kiln; these may pass through horizontal, stout strips of timber on the outside to more effectually apply their retaining force; the rods should be secured at the ends by strong nuts, with large washers. The inner wall should be built of the best fire-brick if the kiln is intended for hard use; sometimes satisfactory substitutes for fire-brick are obtained in sandstone and hard clay-slate found in the

Fig. 2.

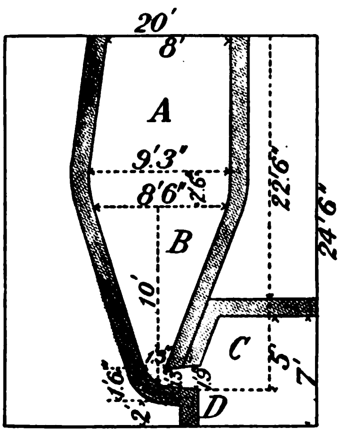
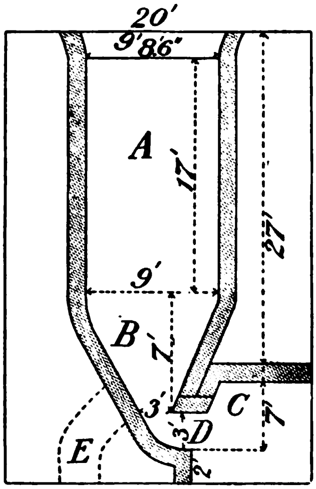


Fig. 2.



A—The body of the kiln; B—The bosh; C—The draw-arch; D—The door; E—Flue proposed by Shortlidge.

locality. The space between the inner and outer walls is commonly filled with well-tamped earth, which serves as a good retaining wall and as an excellent non-conductor of heat. It is often convenient to examine the glowing mass in the middle portions of the kiln and, in case it clogs, as sometimes happens, to be able to stir it down. Both advantages are secured by building into the kiln several two-inch iron tubes that pass from the exterior at convenient points, horizontally through the inner wall; when not in use they are closed by plugs, or caps; they admit a long iron rod by means of which the clogged lime can be poked and worked down. The opening from the interior of the kiln into the draw-arch should be closed by a door, so that the amount of air admitted at that point may be regulated.

By many lime burners the iron shell kiln is being adopted. This is a kiln whose body is formed from boiler iron, lined with fire-brick and supported upon iron pillars or upon an arch of masonry. It may either be simply enclosed within a wooden building or, for better prevention of loss of heat, within a wall of masonry suitably packed with broken stone or earth.

The late Col. Wm. Shortlidge, of McCalmont & Co., the owners of extensive lime kilns at Bellefonte, Pa., a lime manufacturer of many years' experience, mentioned to the writer the difficulty of regulating the draught so as to secure an even calcination, as one of the most serious objections to the ordinary, single-arch draw-kiln. As a remedy, he proposed that a ring flue be constructed with its air inlets opening from the sides of the draw-arch and discharging through three or four vertical branches ending in stout iron gratings. about 9 inches by 12 inches, set at the same height in the sloping walls of the bosh of the kiln, so as to introduce air more uniformly to different parts of the kiln. He had already tried a modification of the old form of kiln in which this feature had been imperfectly introduced, and found it to result beneficially. The location of this flue with one of its branches is dotted into the vertical section, Fig. 3, at E. It would be desirable, the writer would suggest, to provide passages, closed with suitable doors let into the sides of the kiln, constructed at right angles to the axis of the draw-arch, for the annular flue will, in time, be stopped by the fine material that passes through the gratings and this dust must be removed to keep the draught in proper regulation.

The location of the kiln also has much to do with the draught. If the latter be poor, the burning is expensively slow. It is well known in regard to chimneys that if their tops be lower than the roof of the house or than the leafy tops of neighboring trees and the wind pass over the roof or tree top toward the chimney, a down-flow of air pours upon it and effectually checks the upward passage of the heated air from the cap or top. A similar checking of the draught occurs in kilns situated in like manner with reference to a steeply sloping hillside. On the contrary, if the draw-arch face the prevailing wind and be provided with no regulating door, over-burning often results from the occurrence of too fierce a draught.

So important are the points of regulation of draught, fuel proportion and quality of stone and coal to which a skilful burner closely attends, that, according to an experienced lime manufacturer, a flame-kiln of modern construction, with body of oval cross section, 4½ feetx6½ feet, and a height of 22 feet above the fire arch, which will, under most favorable conditions, yield 500 bushels of lime per diem, yields, in actual practice, with ordinary average stone and ordinary conditions, only 200 to 250 bushels. The same authority states that a kiln having been built, it is common experience to be obliged to materially modify arches, door-ways, etc., to adapt the draught qualities of the kiln to the particular movements of wind currents in the locality of this single kiln.

The variation in the quantity of coal required in this type of kiln ranges, according to computations based upon data given by Gilmore,* from 1:2.25 to 7.2 parts of the burnt lime. Frasch** states that for three volumes of the stone, one volume of soft coal, one and one-half volumes of coke or three to four volumes of lignite is required. Magnesian limes† and cements require somewhat smaller proportions of fuel. Gilmore‡ states that 3,500 lbs. of anthracite coal is sufficient for 100 barrels of cement of 300 lbs. each, which is a ratio of one part coal to 8.6 parts calcined cement. The coal should be of a low ash content, if possible, to diminish the danger of "clinkering."

The best calcination occurs when the stone is broken into rather small pieces; this is especially true in burning impure limestones, which should be broken to less than six inches in diameter.

In the operation of the ordinary draw-kiln, kindling is placed upon the grate,§ covered with coal followed by stone, coal and stone alternating to the top of the kiln, which is often surmounted by a wooden crib by which its capacity is increased and the heat more fully utilized. In filling the kiln before the burning has begun, the lower coal layers are made unusually thick in proportion to those of stone, for reasons already suggested in discussing the burning in heaps; later, the normal proportions are maintained. Others prefer to fill the kiln one-half to two-thirds with raw stone, then adding a layer of fuel and subsequent layers of stone and fuel as in the charging during the burning; the fuel layer is in such case connected with a core of kindling running from the draw-arch. The object of this arrangement is to secure a more uniform management of the heat; if, however, the coal layer is not ignited from the kindling, the expense of discharging and recharging the kiln is considerable.

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*On Limes, Hydraulic Cements and Mortars, 1864, p. 141.

***Loc. cit.*,

†Roscoe and Schorlemmer, Treatise on Chemistry, II, Part I, p. 190.

‡*Op. cit.*. p. 127.

§Many draw-kilns have the lower wall of the bosh terminate, as it approaches the door into the draw-arch, in a grating, below which is a shallow pit.

### STAGES OF BURNING.

According to H. Reid* there are two distinct stages in the burning of stone; the first, during which water is expelled and organic matter is destroyed; until this is completed, the indication being the disappearance of vapor readily recognized by the expert eye, the application of high heat is wasteful; the second stage is that of "decarbonatation," and is completed when all the carbonic acid that can be profitably removed has been dispelled, which is accomplished at about the temperature of bright redness.

It is difficult to expel the last portions of carbonic acid. The stone burns more rapidly if it is somewhat moist. Many lime burners have been in the habit of using moist wood or of watering the stone with the object of developing steam to promote the expulsion of carbonic acid.

Frasch observes that fresh-quarried stone burns more perfectly than that which has been long exposed to the air and recommends periodic injections of steam or air. But Mahan† regards the practice as disadvantageous because of the increased fuel requirement.

### BURNING IMPURE LIMESTONE.

Impure limestones are especially difficult to calcine uniformly; those containing sand often vitrify at a temperature not much above dull red heat, and the hard, glossy lumps left on cooling are not only of no use to the builder or farmer, but increase the difficulty of handling the other material.

When very impure clayey limestones are burned, the lime unites with the clay, which, as it occurs in the limestone, is insoluble in acids, and forms by union with it silicates that are completely dissolved by acids. Intimate mixtures of pure limestone and certain clays, when burned together, form similar silicates. The practice of clay-burning followed, a few decades ago, in many parts of England and Germany as a means of improving the soil, is believed to have owed its value to the formation in the burnt clay of similar silicates; clay deficient in lime, was not benefitted by burning.

### TIME OF BURNING.

The length of time required for ignition in the draw-kiln is less than in the intermittent kiln. The lime will be partially drawn every few hours so far as the burner finds it to have been satisfactorily calcined; no absolute time rule can be laid down.

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*Portland Cement, p. 243.

†Civil Engineering, p. 25 *seq.*

According to Frasch a kiln of 1,200 to 1,400 cubic feet capacity will turn out 700 to 900 cubic feet per day of twenty-four hours, if ten to twelve charges be drawn during that period. The lime expands in volume from 20 to 25 per cent. during the burning, but retains the shape of the original stone. Pure lime should be burned rapidly, as it slakes better in such case, but if incompletely calcined it forms a basic lime carbonate and is "dead," or incapable of slaking. Compact limestone cannot be so rapidly calcined as the porous varieties, but yields a better lime.

As the lime is drawn, the major portion of the coal ashes can be thrown to one side, but some will remain admixed with the lime.

## WEIGHT OF LIME.

The weight of a bushel of lime is much more variable than is commonly supposed. Lloyd* says "A ton of lime equals about 27 bushels;" that is, a bushel weight is 75 lbs. Roberts† also says, briefly, "75 lbs. of stone lime are sold for a bushel at the kilns at Union Springs, N. Y."

Cook‡ states that a bushel of good stone lime, unslaked, weighs 93 lbs.; of oyster-shell lime, 60 lbs.; of magnesian stone lime, 80 lbs. Legal weights for a bushel of unslaked lime have been established by several states as follows: In Ohio and Michigan, 70 lbs.; in Virginia, Georgia, Illinois, Iowa, Kansas, Nebraska and Colorado, 80 lbs.§. In Pennsylvania, the more commonly accepted bushel weight is 72 lbs.

In view of the range of these figures, it was thought of interest to inquire somewhat more particularly respecting the accurate weight of a struck bushel of the fresh-burnt limes sold in the State. The replies received from a number of lime burners and dealers are tabulated in the second column of the following table:

TABLE I.—Weight of a Bushel of Lime. (Struck Bushel; in Pounds.)

| Quarry. | Fresh-burned. | Slaked. | Remarks. |
|---|---|---|---|
| **Berks county:** | | | |
| 1. Near Bechtelsville, on Colebrookdale R. R.,<br>M. G. Oberholtzer, Prop'r, ...... | 82 | ............ | Solid, blue stone; 54 c. l., 44, c. m. |
| 2. West branch of Maiden Creek, near Calcium,<br>J. S. Pearson & Co., Prop'r, ..... | 78 | 40 | Stone never analyzed. |
| 3. Near Host, Tulpehocken Twp.,<br>Jacob Shaffner, Prop'r, ........... | 78 | 40 | Stone never analyzed, burns to a fine, white lime fit for building. |

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*Science of Agriculture, p. 119.

†Fertility of the Land, p. 305.

‡Report of the New Jersey State Agricultural Experiment Station, 1881, p. 81.

§*Cf.* Report, U. S. Dept. Agriculture 1880, p. 227.

TABLE I.—Continued.

| Quarry. | Fresh-burned. | Slaked. | Remarks. |
|---|---|---|---|
| Blair county: | | | |
| 4. Near Union Furnace, on main line P. R. R., Keystone Lime and Stone Co., Tyrone, Prop'r, | 72 | 50 | Slaked weight is for dry-slaked lime; analysis: c. l., 96; c. m., 2 per cent. |
| 5. Stanfield Station, Hollidaysburg and Martinsburg Branch, P. R. R., John Manning, Hollidaysburg, Prop'r, | 72 | 30 | Slaked weight is air-slaked; analysis, 98 per cent. c. l. |
| 6. Frankstown, on P. R. R., J. King McLanahan, Jr., Hollidaysburg, Prop'r, | 72 | ............ | Analysis, 94 per cent. c. l., 2 per cent. c. m. |
| Chester county: | | | |
| 7. Near Avondale, Phila. & Balto. Central R. R., Avondale Lime and Stone Co., Prop'r, | 80 | 35 | Stone varies from a pure c. l. (fish egg) to a mica schist; stone burned has some magnesia, as it is the only kind in this quarry that will stay in lump during burning. Average composition, 70-80 c. l.; 15-25 c. m. |
| Franklin county: | | | |
| 8. Near Williamson, on S. Penn. R. R., Isaac Lesher, Prop'r, | 60 | ............ | |
| Lancaster county: | | | |
| 9. At Quarryville, I. Galen Lefevre, Prop'r, | 75-80 | ............ | |
| Lebanon county: | | | |
| 10. One-half mile from Annville, Jno. A. Bachman, Prop'r, | a. 70-75<br>b. 75-80 | 36 or less. | a. soft-burned; b. hard-burned; slaked lime weighs half, or less than half as much as stone lime. |
| Lehigh county: | | | |
| 11. At Fogelsville, A. W. Held, Prop'r, | 100 | ............ | Analysis shows 90 per cent. c. l. |
| 12. Near Egypt, E. D. Boyer, Catasauqua, Prop'r, | 68-70 | ............ | Analysis shows 92 per cent. c. l., 1 per cent. c. m.; adjoins cement rock deposits. |
| Lycoming county: | | | |
| 13. On Pine Creek, near Beech Creek R. R., J. Sebring, Jersey Shore, Prop'r, | 72 | 50 | |
| Monroe county: | | | |
| 14. Boshardsville, Jno. P. Carmer, Prop'r, | 80 | 40 | |
| 15. Boshardsville, Peter M. Heller, Porp'r, | 75 | ............ | Analysis, 94 per cent. c. l., 1.5 c. m. |
| 16. Stormville, Allen Metzger, Prop'r, | 70 | ............ | |
| Montgomery county: | | | |
| 17. Whitemarsh and Plymouth Twps., G. W. H. Corson, Plymouth Meeting, Prop'r, | 70 | ............ | Screenings only sold for farm use |
| 18. Port Kennedy, Todd & Son, Prop'rs, | 70 | ............ | Analysis, 53 c. l., 45 c. m., stone from from Chester Valley dolomite Sell screenings only for farm use rest for building purposes. |
| Northampton county: | | | |
| 19. 1½ miles South of Nazareth, Edw. Fehnel, Prop'r, | 80 | 50-60 | Stone is of a slaty nature. |
| York county: | | | |
| 20. Hendrix Station, Western Md. R. R., Bittinger & Eberly, Hanover, Prop'rs, | 65 | ............ | Analysis, 88 per cent. c. l., 8 per cent. c. m., 4 per cent., carb. of potash. |
| Sussex Co., New Jersey: | | | |
| 21. Montague, Geo. M. Cole, Prop'r, | 80 | about 40 | |
| East Canaan, Conn.: | | | |
| 22. Canfield Bros., Prop'rs; D. T. Gates, Agt., Mansfield, Tioga Co., Pa., | 100 | ............ | The lime is shipped to Penna. in barrels. |

The wide range from 60 to 100 lbs. per bushel is thus reported for stone limes, the average for the twenty-three sorts being 76.2 lbs. There is no clearly distinguishable relation between the composition of the stone and the weight of the lime; compare, for example, Nos. 1 and 18 and Nos. 11 and 12; so that the porosity of the original stone is clearly the most influential factor, to which no doubt the conditions of burning add another potent influence. Thus, Frasch notes that a given volume of lime from a draw-kiln weighed 55 lbs., but the same volume of lime produced from the same stone by calcination in a Hoffman flame-kiln weighed only 50 lbs.

## SLAKING OF LIME.

The general phenomena of *slaking* and its chemical nature have already been mentioned. Limes exhibit, according to the composition of the rocks from which they have been prepared and the manner in which they have been burned, differences in regard to slaking so great that they constitute the basis of the most commonly accepted classification of limes and cements.

### *Gilmore's Classification.*

Gilmore[*] has given the most satisfactory classification for our present purposes. He divides limes and cements into five distinct classes, as follows:

1. Common, or fat, limes: Contain usually less than 10 per cent. of impurities. In slaking, swells to two to three and one-half times original volume; with sufficient water, form a homogenous paste, very soluble in water; the paste will not harden under water or under the air pump, but on standing in the air, whereby calcium carbonate and crystals of calcium hydrate are formed. The paste shrinks greatly in hardening; hence, the need for addition of sand in making mortar.

2. Poor, or meagre, limes: Contain 10 to 25 per cent. of impurities, sometimes as much as 39 per cent. Slake sluggishly, unevenly and with much less heat and swelling than fat lime. Paste less perfectly soluble. Silica is present chiefly as sand.

3. Hydraulic[†] limes: Seldom contain 35 per cent. of impurities. Slake, but with little disengagement of heat or vapor and swelling rarely more than one-third of the original volume. They are subdivided as follows:

   a. Limes slightly hydraulic; impurities, 10-20 per cent.; stiff paste, hardens under water in fifteen to twenty days.

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[*] *Op. cit.*, p. 69 *seq.*

[†] By *hydraulicity* is meant the property of setting or hardening under water.

several inches of fresh, moist soil from an upturned furrow slice, it will take from the earth all the water needed for slaking to a fine powder. If, however, heaps of 25 to 200 bushels are to be slaked, it is well, after covering with a heavier layer of moist soil, to make small openings into the center of the mass by use of a crow-bar and to pour in water through these openings. The steam formed will perfectly slake the lime in all parts of the heap.

### *Weight of Slaked Lime.*

Concerning the volume occupied by water-slaked lime, Dr. Geo. H. Cook[*] states that 1 bushel of good stone lime weighing 93 lbs., slakes to nearily 3 bushels, each of about 45 lbs. weight; that a bushel of oyster-shell lime weighing 60 lbs. forms somewhat over 2 bushels of slaked lime, each of about 40 lbs. weight, and that 1 bushel of magnesian lime, weighing 80 lbs., yields 2 bushels of slaked lime, each of 40 lbs. weight. It is evident, however, that the conditions of burning, purity, etc., of the lime and the conditions of slaking also greatly modify the changes in volume occurring during slaking. Thus, Gen. Totten[†] states, as the result of many trials that one volume of quick-lime yields, when slaked with one-third volume of water, 2.27 volumes of powder; with two-thirds volume of water, 1.74 volumes powder; with three-fourths volume of water, 1.81 volumes of powder; and with an equal volume of water, 2.06 volumes of powder.

### *Air-Slaking.*

There is another process of slaking to which attention must, in this connection, be especially directed, that of *air slacking.* When caustic lime is exposed in lump to the action of the air it gradually slakes and falls to powder as a result of the absorption of moisture from the atmosphere. At the same time with the absorption of moisture, carbonic acid is also taken up and more or less of the lime returns to its former state of combination as carbonate, though now in a finely powdered form, instead of compact as in the stone. Consequently, such lime is possessed of less causticity. Gilmore[‡] says that while in a layer of ten to twelve inches thickness, some limes completely air slake in twenty to twenty-five days, others would require as many weeks and some a year. In mortar, the carbonate forms first on the outer surface and then more slowly in the interior. Vicat[§] states that this layer is only .10 to .12 inches deep at the end of a year, and Reid[||] further asserts that analyses of mortars taken from buildings erected more than a century before, still show that a portion of the lime in the interior of the mortar has never been carbonated, the solidification or "setting" of the mortar being more largely due to the crystallization of the calcium hydrate than to its conversion into the solid carbonate.

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[*] *Loc. cit.*

[†] Gilmore, Lime, Hydraulic Cements, etc., p. 184.

[‡] *Op. cit.*, p. 183.

[§] Gilmore, *Op. cit.*, p. 187.

[||] *Op cit.*

Lime exposed, in small heaps in the field, to the action of heavy rains and of the air, falls to a powder more or less coarse, containing a large proportion of carbonate. Even when covered with a thin layer of earth, some carbonate is formed. In a heap of pure lime thus slaked, Voelcker[*] found over 15 per cent. of calcium carbonate.

H. J. Wheeler[†] states that dry, fine, air-slaked lime, such as has been bought from time to time by the Rhode Island Experiment Station, has been found to contain but 68 to 75 per cent. of the caustic lime (calcium oxid).

The practice of covering during slaking is much to be preferred and, where possible, that of slaking in one large heap, rather than in a number of small piles. At all events, lime should be exposed in uncovered heaps no longer than is necessary for the slaking to a fine powder, after which it should be promptly distributed and worked into the soil.

The change in volume during air-slaking is even greater than that which is caused when the lime is slaked by sprinkling. Reference to the table giving the bushel weights of fresh-burned and slaked limes produced or on sale in Pennsylvania shows that they range from 30 to 60 pounds, averaging over 40 pounds.

### TESTS FOR QUALITY OF LIMESTONE.

If it be desired to make some test of limestone to determine its quality, spalls should be taken from a freshly exposed surface of the stratum to be tested; these should be broken fine and a carefully weighed or measured portion heated with a dilute acid. The acid used may be muriatic (hydrochloric), nitric or acetic; a liberal amount of good strong vinegar may be used. The heating should be carried on in a porcelain-lined or granite-ware cup. If carbonate of magnesia be present in large proportion, the stone will not bubble or effervesce strongly upon the addition of cold acid, as it would were the stone composed chiefly of carbonate of lime with insoluble impurities only. The acid solution may be carefully poured off after heating. The insoluble residues left in the cups by different strata can then be roughly compared, and their nature as clay or sand noted.

Or, larger pieces of the stone may be burned in a coal fire; the calcined stone, better the inner portion of it, may then be treated with water to note its slaking properties, the liberation of high heat, great swelling and final formation, if the water be added in proper proporthem. In the following table, compiled by Johnson,* a general statement is given of the composition of the ashes of the ordinary crops as they are at time of harvest, and will suffice to exhibit the more important differences in their lime content:

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[*] *Cf.* Lloyd, Science of Agriculture, p. 114.

[†] R. I. Agr. Exp. Sta. Bull. 46, p. 100.

TABLE II—Composition of Ashes from Principal Classes of Crops.

| | Potash and soda. | Magnesia. | Lime. | Phosphoric acid. | Silica. | Sulfuric acid. | Chlorin. |
|---|---|---|---|---|---|---|---|
| CEREALS— | | | | | | | |
| Grain, | 30 | 12 | 3 | 46 | 2 | 2.5 | 1 |
| Straw, | 13-27 | 3 | 7 | 5 | 60-70 | 2.5 | 2 |
| LEGUMES— | | | | | | | |
| Kernel, | 44 | 7 | 5 | 35 | 1 | 4 | 3 |
| Straw, | 27-41 | 7 | 25-39 | 8 | 5 | 3-6 | 6-7 |
| ROOT CROPS— | | | | | | | |
| Roots, | 60 | 3-9 | 6-12 | 8-8 | 1-4 | 5-12 | 3-9 |
| Tops, | 37 | 3-16 | 10-35 | 3-8 | 3 | 6-12 | 5-17 |
| GRASSES— | | | | | | | |
| In flower, | 33 | 4 | 8 | 8 | 35 | 4 | 5 |

These figures show clearly that the straw is, weight for weight, richer in lime than the grain, and the tops of the root crops richer than the roots; also, that the straw of legumes, such as peas, beans and clover, is richer in lime than that of the grasses and common cereals.

## LIME REMOVED BY CROPS.

Taking into account the average amounts of ash in the various farm crops and the composition of the several ashes, using American analyses for the computation of the several averages, where they are available, the quantities of the various plant constituents that are removed from the soil by the respective crops, are as follows:

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*How Crops Grow, 1890, p. 171.

## TABLE II—Weights and Composition of Ordinary Crops in Pounds per Acre.

| | Weight as harvested. | Nitrogen. | Phosphoric acid. | Potash. | Lime. | Magnesia. | Iron oxid. | Sulfuric acid. | Soda. | Chlorin. | Silica. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Meadow hay (1½ tons), | 3,000 | 37.8 | 13.6 | 50.9 | 30.4 | 13.1 | 3.0 | 9.9 | 7.0 | 11.8 | 54.8 |
| Timothy hay (1½ tons), | 3,000 | 25.3 | 21.0 | 64.6 | 14.3 | 5.8 | 1.5 | 5.1 | 3.2 | 9.2 | 57.1 |
| Clover hay (2 tons), | 4,000 | 79.40 | 22.4 | 75.0 | 81.1 | 25.3 | 2.5 | 7.5 | 4.6 | 8.8 | 6.3 |
| WHEAT— | | | | | | | | | | | |
| Grain (25 bus.), | 1,500 | 28.3 | 12.4 | 8.2 | 0.9 | 3.2 | 0.3 | 0.1 | 0.6 | 0.1 | 0.5 |
| Straw, | 2,500 | 13.6 | 5.8 | 16.6 | 7.0 | 3.0 | 0.7 | 3.0 | 1.7 | 2.0 | 81.9 |
| | 4,000 | 41.9 | 18.2 | 24.8 | 7.9 | 6.2 | 1.0 | 3.1 | 2.3 | 2.1 | 82.4 |
| RYE— | | | | | | | | | | | |
| Grain (30 bus.), | 1,680 | 28.5 | 14.8 | 10.0 | 0.9 | 3.5 | 0.4 | 0.4 | 0.5 | 0.1 | 0.4 |
| Straw, | 2,000 | 9.6 | 5.4 | 18.7 | 6.8 | 2.6 | 1.6 | 3.5 | 1.4 | 1.8 | 40.8 |
| | 3,680 | 38.1 | 20.2 | 28.7 | 7.7 | 6.1 | 2.0 | 3.9 | 1.9 | 1.9 | 41.2 |
| OATS— | | | | | | | | | | | |
| Grain (50 bus.), | 1,600 | 30.2 | 11.4 | 8.0 | 1.6 | 3.2 | 0.5 | 0.8 | 0.7 | 0.4 | 17.4 |
| Straw, | 2,100 | 13.4 | 6.3 | 39.4 | 9.5 | 5.0 | 1.6 | 4.4 | 4.5 | 6.0 | 63.8 |
| | 3,700 | 43.6 | 17.7 | 47.4 | 11.1 | 8.2 | 2.1 | 5.2 | 5.2 | 6.4 | 81.2 |
| BARLEY— | | | | | | | | | | | |
| Grain (50 bus.), | 2,350 | 46.6 | 19.2 | 11.7 | 1.4 | 4.8 | 0.6 | 1.0 | 1.3 | 0.5 | 14.2 |
| Straw, | 2,800 | 13.7 | 5.4 | 29.6 | 9.2 | 3.3 | 1.4 | 4.9 | 4.5 | 4.1 | 64.9 |
| | 5,150 | 60.3 | 24.6 | 41.3 | 10.6 | 8.1 | 2.0 | 5.9 | 5.8 | 4.6 | 79.1 |
| CORN— | | | | | | | | | | | |
| Kernel (50 bus.), | 2,800 | 46.1 | 16.40 | 10.80 | 0.80 | 5.60 | 0.30 | 0.30 | 0.40 | 0.30 | 0.80 |
| Cobs, | 700 | 2.7 | 0.04 | 0.42 | 0.02 | 0.03 | 0.01 | .......... | 0.24 | .......... | .......... |
| Stover, | 2,300 | 14.0 | 8.74 | 3.82 | 11.50 | 5.98 | 3.04 | 5.75 | 1.15 | .......... | 41.17 |
| | 5,800 | 62.8 | 25.18 | 15.04 | 12.32 | 11.61 | 3.35 | 6.05 | 1.79 | 0.30 | 41.97 |

TABLE II—Continued.

| | Weight as harvested. | Nitrogen. | Phosphoric acid. | Potash. | Lime. | Magnesia. | Iron oxid. | Sulfuric acid. | Soda. | Chlorin. | Silica. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| POTATOES— | | | | | | | | | | | |
| Tubers (200 bus.), | 14,000 | 47.0 | 18.9 | 67.2 | 3.0 | 5.5 | 1.2 | 7.3 | 3.3 | 3.9 | 2.3 |
| Haulm, | 4,500 | 21.1 | 6.8 | 18.8 | 28.1 | 14.2 | 2.5 | 5.4 | 2.0 | 3.7 | 6.7 |
| | 18,500 | 68.1 | 25.7 | 86.0 | 31.1 | 10.7 | 3.7 | 12.7 | 5.3 | 7.6 | 9.0 |
| SUGAR BEETS— | | | | | | | | | | | |
| Roots (20 tons), | 40,000 | 115.2 | 25.2 | 109.9 | 12.6 | 16.3 | 2.4 | 8.7 | 18.5 | 9.9 | 4.7 |
| Tops, | 20,000 | 76.0 | 23.3 | 129.0 | 99.2 | 55.6 | 2.6 | 26.0 | 67.5 | 41.6 | 49.9 |
| | 60,000 | 191.2 | 48.5 | 238.9 | 111.8 | 71.9 | 5.0 | 34.7 | 86.0 | 51.5 | 54.6 |
| MANGELS— | | | | | | | | | | | |
| Roots (25 tons), | 50,000 | 112.0 | 29.4 | 180.1 | 12.9 | 37.6 | 2.6 | 10.4 | 56.1 | 34.3 | 7.1 |
| Tops, | 18,500 | 51.8 | 16.7 | 79.1 | 27.5 | 24.6 | 3.6 | 14.5 | 50.1 | 41.2 | 9.3 |
| | 68,500 | 163.8 | 46.1 | 259.2 | 40.4 | 62.2 | 6.2 | 24.9 | 106.2 | 75.5 | 16.4 |
| TURNIPS— | | | | | | | | | | | |
| Roots (20 tons), | 40,000 | 70.4 | 38.7 | 138.2 | 32.3 | 11.2 | 2.5 | 34.0 | 29.9 | 15.4 | 5.7 |
| Tops, | 11,600 | 49.8 | 13.2 | 42.4 | 59.5 | 7.1 | 2.9 | 17.0 | 17.1 | 18.3 | 6.9 |
| | 51,600 | 120.2 | 51.9 | 180.6 | 91.8 | 18.3 | 5.4 | 51.0 | 47.0 | 33.7 | 12.6 |
| SWEDES— | | | | | | | | | | | |
| Roots (16 tons), | 32,000 | 61.4 | 18.4 | 69.0 | 21.5 | 7.4 | .......... | 39.8 | 24.8 | 7.4 | 3.4 |
| Tops, | 4,800 | 28.6 | 4.9 | 16.7 | 23.1 | 2.4 | .......... | 8.2 | 9.4 | 8.5 | 3.7 |
| | 36.800 | 90.0 | 23.3 | 85.7 | 44.6 | 9.8 | .......... | 48.0 | 34.2 | 15.9 | 7.1 |
| Cabbages (20 tons), | 40,000 | 153.6 | 48.6 | 199.2 | 95.3 | 21.6 | 3.7 | 75.2 | 53.2 | 46.1 | 4.7 |
| Onions (500 bus.), | 28,500 | 63.8 | 32.4 | 63.5 | 42.7 | 8.7 | 4.2 | 10.6 | 4.6 | 4.5 | 15.9 |
| Tobacco (leaf), | 1,500 | 58.8 | 10.8 | 67.3 | 83.4 | 17.0 | 4.5 | 14.1 | 7.4 | 15.5 | 13.4 |

## DISTRIBUTION OF LIME IN THE PLANT.

The kinds and quantities of ash constituents in any given part of the plant are not constant, but vary not only with the species and variety of the plant, and with the conditions under which it grows, but also in the same plant during its development. A number of interesting observations have been made upon the movements of lime in various plants, of which a few may be cited.

Of the various organs, the leaves are richest in lime, except in the case of trees, whose bark surpasses the leaf.

The investigations of Arendt[*] show 16.7 and 17.2 per cent., respectively, in the lower and upper leaves of the oat plant, while the stem contains 3.6 to 8.6 per cent., and the ears 7.3 per cent. The older leaves usually contain far more than those of less maturity. Thus, Bretschneider,[†] comparing the inner, or younger, leaves of the sugar beet with the outer, or older, leaves, found in the innermost only 4.7 per cent., as compared with 24.2 per cent. in the outermost. Another of many illustrations of this fact is found in the case of the chestnut. Fliche and Grandeau[‡] found in leaves taken May 1, 18.41 per cent. of lime, and in others taken October 12, 49.50 per cent., while the percentage of magnesia differed little, and those of potash and phosphoric acid were greatly diminished in the older leaves.

Studying the changes that occur during the development of the grain of oats, Arendt[§] obtained results indicating a transfer of lime with potash from the grain as it matures, while magnesia and phosphoric acid are transferred in large quantity from the leaves to the grain.

Lime and magnesia, which bears so much resemblance to it in its chemical reactions, are also very differently distributed in the grain of cereals, as shown by the analyses of bolted wheat flour and bran, from which it is clear that the inner portion of the endosperm from which the finer flour is prepared, contains most of the lime, while magnesia occurs chiefly in the bran. Owing to the relatively small quantity of lime in the seed, as compared with that in the leaf, it is not surprising that Boehm,[||] Von Liebenberg,[**] Dehérain and Bréal[††] have discovered that under ordinary conditions of germination, lime is the first ash constituent required to be supplied from the soil in order that the processes of vegetation may be completed.

In the sprouting of the tubers of potatoes, Kellermann[‡‡] found, on the other hand, that while the total ash, potash and phosphoric acid in the tubers steadily decreased for fourteen weeks, the quantity of lime increased five fold, being taken up from the soil and held in the old tuber in the form of calcium oxalate, the continuous secretion of oxalic acid and formation of the oxalate accounting for the absorption of the lime.

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[*] *Cf.* Johnson, How Crops Grow, 1890, p. 171.
[†] *Ib.* p. 172, from Hoff. Jahresbericht, 4, 89.
[‡] Ann. chim. phys. (5) 8, 500; Deherain, Chimie agricole, 1892, p. 156.
[§] *Op. cit.*, p. 237.
[||] Ann. agron., I., 470.
[**] *Ib.* 8, 58.
[††] *Ib.* 9, 127.
[‡‡] *Ib.* 4, 615.

Desbarres,* in studying the development of new wood of the sumac. found little change in the composition of the ash.

## COMPOUNDS OF LIME IN PLANTS.

The condition in which it exists in the plant, varies with the species and the circumstances of its growth. When the plant is young and the lime is not present in excess, it is largely combined with the acids characteristic of the species in the form of an acid salt, present in solution in the sap. The acid malate of lime sometimes occurring so abundantly in maple sap and known to maple sugar makers under the names of "sand" and nitre," is an interesting example of this kind of compound.

## LIME SOMETIMES PRESENT IN EXCESS.

When a soluble salt of lime with a mineral acid is taken up in excess by the plant, a portion of it may be excreted through the leaf, to be washed off by the rain, as was observed by Saussure† in the case of calcium chlorid upon the leaves of the cucumber.

Certain rather difficultly soluble compounds of lime and albuminoids are found in grains and as calcium carbonate unites with some of the group of organic substances of which starch, wood and sugar are members,it is believed by some investigators that similar chemical compounds occur within the plant.

When lime is present in large quantities, much of it is present in the form of saline encrustations or in crystals. Potato leaves often contain considerable quantities of solid calcium carbonate, which is also often found in wood and bark. In dense teak wood,‡ concretions of calcium phosphate are often found, while 80 per cent. of the dry matter of *Cactus senilis* is composed of calcium phosphate and oxalate. The leaves of the walnut, the leaf stem of the rhubarb and the beet root often afford beautiful specimens of crystalline calcium oxalate. Sachs found in the root of the young bean, crystals of calcium sulfate. The *Saxifraga crustata*, a low European plant found in lime soils, is covered by a scaly encrustation of calcium and magnesium carbonates, which Unger§ found to proceed from granular expansions on the margin of the leaf directly connected with the sap ducts; in soils poor in lime, the encrustation does not appear.

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*Dehérain, Chimie agricole, p. 61.

†Recherches sur la Veg. p. 265; Johnson, How Crops Grow, p. 203.

‡*Cf.* Johnson, How Crops Grow, pp. 204, 206.

§Sitzungsber. Wien. Akad.,

Berthier[*] makes the interesting observation that rye, which grows well on granitic and siliceous soils, contains, in the ash from the mature straw, calcium only in the form of phosphate, while the ash of barley, which grows upon such soils only after they have been limed, contains not only as much calcium phosphate, but also a percentage of calcium carbonate much larger than that of the phosphate.

### USES OF LIME IN THE PLANT.

The functions performed in the plant by lime are not clearly defined. That it is useful in neutralization of plant acids and in their removal, in the form of insoluble, neutral salts, when in excess in the sap, has already been made apparent. Grübler[†] has observed the occurrence of both calcium and magnesium in the aleurone grains of seeds, where they occur as soluble, crystallizable compounds with the albuminoids, whose diffusibility they thus promote.

There is evidence to indicate that, while lime is not essential to the formation of starch in the leaf, it is useful in the normal formation of cellulose. Boehm[‡] and Von Raumer[§] made a series of observations upon the germination of the scarlet runner (flowering-bean, *Phaseolus multiflorus.*) Germinating it, keeping its roots in pure water and its leaves in the darkness, the young shoots are seen to develop without green color, but perfect in form, for a number of days, when, suddenly, there appears just below the terminal bud, a discoloration, and the stem wilts, withers and dies; yet the cotyledons, or seed lobes, are still unexhausted of their supply of starch, the reserve building material from which the wood of the cell walls is derived. If, however, instead of placing the roots in pure water, they be inserted in a dilute solution of any lime compound (except the chlorid), the plants maintain the stem development until the starch in the seed is completely exhausted. According to Boehm, carbonate of magnesia, instead of being able to replace lime for this purpose, is positively poisonous. Von Liebenberg[||] has extended these observations with similar result to the seeds of a number of plant species.

On the other hand, Dehérain and Breal,[**] observed that while lime is beneficial to normal germination and indispensable to normal stem development at the ordinary temperatures of germination in the soil, the seed is able, at slightly elevated temperatures (86 degrees to 95 degrees Fahr.), to continue a healthy stem development until the starch in the seed has been exhausted, without the presence of any lime except the small amounts already present in the seed. Storer[††] notes, further, the fact that cellulose formation is carried on in certain fungi, such as beer-yeast, in the entire absence of lime, the fact having been established by the researches of A. Mayer and Cohn; Storer, therefore, suggests that lime is indispensable for the proper formation of leaves, rather than for that of cellulose in general. Heinrich,[*] however, inclines to the opinion of Boehm, and notes the almost invariable incrustation of the cell membranes with lime compounds, an incrustation which becomes thicker as the cell grows older, especially in the case of woody cells. Loew[†] and Bokorny[‡] regard it as playing an important part in the chlorophyll granules and of the nuclei, or reproduction centers, parts of the highest importance in the life of the plant.

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[*] Dehérain, Chimie agricole, 158-9.

[†] Johnson, How Crops Grow, 1890, p. 216.

[‡] Jb. Ag. Chem., 1875-6, I, 255; Ann. agron. 1, 470.

[§] Vers. Stat., 29, 251.

[||] Ann. agron., 9, 127.

[**] Ann. agron., 9, 58.

[††] Agricultural Chemistry, 1892, II, 407.

### EFFECT UPON FORM OF PLANTS.

R. Heinrich[§] notes that lime has a marked influence upon the external forms of vegetation; when lime is abundant in the soil, the internodes between the leaf axils are shorter and thicker, and the plants set more abundant and vigorous stalk organs and tend to heavier fruiting, whereas upon soils deficient in lime, plants shoot up in slim stalks and, though often blooming abundantly, set fruit deficiently.

E. W. Hilgard,[||] speaking of the character of the growths of the several species of oaks ("post," "black jack," "scarlet" and "white") upon strong and upon light soils in Mississippi, notes that upon the former soils, the growths are sturdy, thick-set, with short, stout branches and dense tops; while on the poorer soils the growths are more slender, often very crooked and knotty, with slender branches and open or tattered top.

### CALCIPHILE AND CALCIFUGE PLANTS.

It has been noted that certain plants, such as the sugar beet and common red clover, flourish particlarly well in soil containing abundance of lime; hence, such plants are called "calciphile," or lime-loving. Others, such as the sorrel (*Rumex . acetosella*), sea pine, chestnut and lupin, either grow with less luxuriance upon lime soils than upon soils deficient in this ingredient, or are injured or absolutely destroyed by liming. Such plants are called "calcifuge," or lime-avoiding. The growth of such plants as indicative of the nature of the soil and in its relation to the agricultural application of lime will be considered in another connection. It is of interest here to note that the calcifuge plants are not devoid of lime, but often contain large amounts of it. Thus, the ash analyses of the sugar beet, compiled by Wolff, show in the ash of the root 6 per cent., and of the top 20 per cent. of lime, while those of the lupin show in the seed ash 7.5 per cent. and in that of the straw about 23 per cent.; that is, the proportion of lime in the ash of the calcifuge plant was actually the larger. If, in like manner, a comparison be made between the ashes of the chestnut and of the white oak, the latter growing especially well upon calcareous soils, it is found that the ashes of the chestnut contain, the bark 47 per cent., the wood 49 per cent. of lime, and those of the white oak, the bark 52.73 per cent., and the wood 29.85 per cent. of lime.*

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[*] Mergel u. Mergeln, 1896, 4.

[†] Flora, 1892, Heft. 3.

[‡] Bot. Centralbl., 62, 1.

[§] Mergel u Mergeln, 1896, p. 6.

[||] X Census, 5, 229.

Fliche and Grandeau† have made an interesting study of the composition of the sea pine. This tree prospers only on soils quite poor in lime. Analyses were made of twigs (1) taken from a tree growing on a soil containing .05 per cent. of lime in the surface, and 0.20 per cent. in the sub-soil; (2) from a tree growing in a soil containing in the surface 3.25 per cent., and in the sub-soil 24.04 per cent.; (3) for comparison, the composition of the ash of the Austrian black pine, growing well on lime soil, was determined; the percentages of lime were (1) 40.2, (2) 56.1, (3) 49.1; that is, the ash of the calcifuge plant contained about as much lime as the calciphile when both grew upon soils best adapted to their normal development. When the sea pine was grown upon a calcareous soil, its content of lime was abnormally increased, and, curiously, the percentage of potash was reduced two-thirds; the loss of vigor is probably due to the deficiency of potash. Bernard,‡ in his studies upon the vine, which, especially the native vines of France, is subject to a very destructive disease manifest through the leaves and termed "chlorosis," states that it is caused by excess of lime in the soils. When the grape leaves are examined, they appear to contain numerous crystals of calcium oxalate, and, like other calcifuge plants, show a similar tendency to throw out of circulation the excess of lime in their tissues. The juices of chlorotic grapes also appear less acid than normal and sometimes even clearly alkaline. When the chlorosis is cured, the crystals of calcium oxalate disappear.

## V. LIME IN SOILS.

### COMPOUNDS OF LIME PRESENT.

In earlier paragraphs treating of the formation of limestones, the fact was noted that lime is one of the rock substances more easily taken into solution when rocks weather or decay. It forms somewhat readily soluble compounds with chlorin, nitric, sulfuric, carbonic acid and with certain organic acids; less soluble with other organic acids, phosphoric acid and, in certain hydrous double compounds, with silica and alumina, while its anhydrous compounds with silica are the most insoluble combinations into which it enters.

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*Cf. Handbook of Exp. Station Work, 1893, p. 411.

†Ann. chim. phys., (4), 29, 383.

‡Le Calcaire, 1893.

Considering the great variety of mineral substances from whose weathering and pulverization soils have been formed, with the modifying influences of the varying nature of the surface of the country and the varying extent to which living organisms have been active in the soil formation, it is not surprising that soils should exhibit a very wide difference in their content of lime.

## PROPORTION IN VARIOUS SOILS.

The following list of soils, with the proportion that they contain of lime soluble in hydrochloric acid, serves to exhibit the great differences:

TABLE IV—Percentage of Lime in Various Soils.

| Kind of Soil. | | Lime. Per cent. |
|---|---|---|
| 1. Prairie soil from North Dakota, | | .85 to 3.90 |
| 2. Virgin soil from Walla Walla; fertile, sandy, from basaltic rock, | | 1.34 to 2.10 |
| 3. Muck, from Union Pier, Mich., | | .97 |
| 4. Heavy prairie swamp, with clay subsoil; yields large crops of hay, fair wheat, poor corn, | | 1.29 |
| 5. Subsoil corresponding to No. 4, | | 1.23 |
| 6. Drift soil, with clay subsoil, Oswego, N. Y., | | .35 to 1.87 |
| 7. Alluvial bottom soil, Louisiana, | | .41 to 3.06 |
| 8. Barren, pine-hill land, Louisiana, | | .09 |
| 9. Sandy soil, Rio Grande, N. J., | | .225 to .505 |
| 10. Soils from Kansas and Nebraska, prairie, | | .45 to .76 |
| 11. Sugar-cane soil, Demerara, cropped 15 years, | | .08 |
| 12. Sugar-cane soil, Jamaica, | | .99 |
| 13. Rhine alluvium, Zuider Zee, Holland, highly fertile, | Surface, | 4.09 |
| | 15 in. deep, | 5.10 |
| | 30 in. deep, | 2.48 |
| 14. Fertile wheat soil, Mid Lothian, Scotland, | | 1.23 |
| 15. Sterile soil, Upper Palatinate, Bavaria, | | .10 |
| 16. Ten sandy soils, from Alabama, Florida and Georgia, | | .045 to .141 |
| 17. Ten clay soils from Alabama, Georgia, South Carolina, Mississippi, Tennessee and Louisiana, | | .036 to 3.054 |
| 18. Average of 466 non-calcareous soils of humid region of the U. S. (S. C., N. C., Ark., Ky. and Gulf States), | | .11 |
| 19. Average of 313 soils of arid region of the U. S. (Cal., Wash., Montana), | | 1.36 |
| 20. Alkali soils of California, Washington and Montana, | | .03 to 4.50 |
| 21. Black tschernosem, Poltava, Russia (wheat soil), | | 1.21 |
| 22. Volcanic soil, gray, Sumatra (tobacco soil), | | .77 |
| 23. Granitic soil, Granville, N. C. (yellow tobacco soil), | | .07 |
| 24. Limestone soil, Donegal, Pa., | | .61 |
| 25. Limestone soil, Rocky Spring, Pa., surface, | | .41 |
| 26. Limestone soil, Rocky Spring, Pa., subsoil, | | .25 |

Note.—These analyses are quoted from the following sources: Nos. 1-8, Richards, Bulletin No. 9, Chemical Division, U. S. Dept. of Agriculture; Nos. 9-12, Richardson, Special Report on the Investigation of Sorghum, 1892 (U. S. Dept. Agr.), pp. 58-64; Nos. 10-15, Johnson, How Crops Feed, pp. 363 and 366; Nos. 16-17, Hilgard, quoted by King, The Soil, pp. 84-87; Nos. 18-20, Hilgard, Bull. 3, U. S. Weather Bureau; Nos. 21-26, Frear, Rep. Pa. Ag. Exp. Station, 1894.

It is clear from these analyses that fertile soils usually contain 0.2 per cent. or upward of lime and that soils containing as little as 0.1 per cent, are usually marked for their barrenness. The texture of the soil, since it affects the ease of extension of the plant roots, has some determining power over production; a loamy soil, through which roots readily distribute may be fairly productive with a low lime content that would cause sterility in a compact clay. On the other hand, since rain passes more readily by percolation through the former soil, it is more easily reduced by drainage to the lower limit of productiveness where the location of the soil favors leaching; sands are usually much less rich in lime than clays are.

The above illustrations do not exhibit the greatest extremes of lime percentage in soils; sea dunes often show a lower percentage, while coral sands, chalky and marly soils exhibit much higher ones; the writer has analyzed a soil from Juniata county, in this State, that contained upwards of 90 per cent. of calcium carbonate.

## LIMESTONE SOILS NOT ALWAYS RICH IN LIME.

It is a common inference that soils derived from limestone formations are necessarily rich in lime; but this is very often not the case, owing to the relative ease with which calcium carbonate dissolves in the carbonated waters of the air. Merrill[*] remarks that thousands of feet of such strata may disappear without leaving more than a very thin coating of soil in their place. Penrose,[†] from the examination of an impure limestone and its residual clay, found that the latter represented only 2.365 per cent. of the former and that, of the lime, 98.93 per cent. was lost, the rock containing 44.79 per cent., the clay 3.91 per cent. Bernard[‡] cites two soils which their owners thought to be rich in lime because derived from limestone rocks, viz: From the Forest marble strata, 92.60 per cent. calcium carbonate, soil, 3.28 per cent.; Cornbrash strata, rock, 91.30 per cent., soil 0.40 per cent. Possibly the most striking illustration of this sort is that given by Spencer,[§] who finds in a sandy soil on the slopes of the Alleghenies 0.14 per cent. of lime, whereas the parent limestone contains over 30 per cent.

## LIME IN COARSE AND FINE PARTS OF SOIL.

Some facts concerning the condition of the lime in different soils may be noted. Bernard,[||] from the examination of over one hundred soils of Jurassic origin from the district of Saone-et-Loire, France, finds equal percentages of lime in the several portions as to fineness, into which each soil was divided by sifting. In these soils, the lime is supposed to have been deposited with organic remains. But in certain soils from Cretaceous formations the percentage of lime is much larger in the finer than in the coarser portions of the soil; Bernard believes this difference is due to a chemical precipitation of the lime in the latter soils.

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[*] Rocks, etc., pp. 231-2.

[†] Annual Report Geol. Survey, Arkansas, 1890, p. 179.

[‡] Le Calcaire, pp. 120-130.

[§] Report of the Geological Survey of Georgia.

[||] Le Calcaire, pp. 46-58.

### LIME IN SURFACE AND SUBSOILS.

Despite the influence of cropping and leaching, the surface soil usually contains more lime than the corresponding sub-soil. King,* taking the averages of a number of analyses of sand and clay soils finds in the sand: Surface, .115 per cent.; sub-soil, 0.096 per cent.; clay, surface, 1.761 per cent.; sub-soil, 1.481 per cent. This is doubtless due to the abundance of lime dissolved in the soil water and brought by the wick-like action of the soil to the surface, where it is left upon the evaporation of the moisture. The effect of such upward translocation is distinctly seen in comparing the soils of the humid and the arid regions, the upward movement of soluble matters being uncompensated in the latter climate by the leaching effect of rains. To the resulting abundance of lime in these soils, upland and lowland, Hilgard attributes their high and very uniform productiveness when they are irrigated.

### SOLUBILITY OF LIME.

The condition of ready solubility of lime in the soil is indicated by the fact that on examination of the results of aqueous extraction of seventeen soils discussed by Johnson,† lime was found to make up from 6 to 25 per cent. of the solid extract, being the most abundantly extracted base, constituting 20 per cent. or more of the solid extract in seven out of the seventeen cases. This is further shown by the analyses of drainage waters by Way‡ and of lysimeter waters by Zöller,§ the extracts in the former containing 10 to 25 per cent. of lime, and those of the latter 22 to 32 per cent. Magnesia was much less abundantly dissolved, and, usually, potash was more abundant when the percentage of lime was high. Moreover, Ulbricht,|| in examining the solubility of the several constituents of various soils upon repeated extraction with water, has shown that lime, more than any other constituent, maintains its readiness of solution.

The lime which is removed from the soil by water is chiefly in combination as the carbonate, sulfate, nitrate, chlorid or phosphate. Very dilute acids remove it in scarcely greater quantities than are represented by its compounds, in the soil, with the above-named acids. Much larger quantities are extractible by the use of moderately strong acids; in such cases, considerable quantities of soluble

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*The Soil, p. 85.

†How Crops Feed, pp. 310-312.

‡Jour. Roy. Agri. Soc., 17, 133; quoted by Johnson, *Op. cit.*; p. 313.

§Quoted by Johnson, *Op. cit.*, p. 315.

||Versuchs-Stat., 5, 207.

silica and alumina are also liberated. It is inferred that the lime was present in combination with the silica and alumina, probably in the hydrous silicates known to mineralogists as the zeolites, which are readily decomposed by moderately strong acids with the production of soluble silica. Thus, Hilgard[*] notes that in the prairie soils of Alabama, Mississippi and Texas, a large percentage of lime is accompanied by high percentages of soluble silica and alumina. In some cases 1 or even 2 per cent. of lime is present, and in the mulatto clay lands of Tennessee, 6.5 to 8.4 per cent., and scarcely a trace of carbonic acid is found; in these cases, the lime is probably present as a zeolitic silicate.

### RELATION TO ORGANIC MATTER.

The relation of the lime in soils to the organic matter is one of extreme variability. In the soils analyzed by Richards (see preceding table), the proportion of lime to organic matter varied from 1:1.5 in a light, fertile basaltic soil from the State of Washington, to 1:37 in a cultivated peat from Berrien county, Mich. Infertility not infrequently occurs where the ratio of organic matter is 20 or higher. Tacke[†] bases his classification of moor soils upon their lime content, the characters and treatments corresponding. His classes are: (1) upland moor, 0.5 per cent. lime; (2) intermediate moor, 0.5 to 2.5 per cent. lime; (3) lower, or meadow, moor, over 2.5 per cent. lime. It is notable that despite the facts that the acids of the humus, such as the humic, ulmic, apocrenic and crenic, have the power to decompose calcium carbonate with the formation of calcium humates, ulmates, apocrenates and crenates, and that the first three of these classes of compounds are very difficultly soluble in water, the tendency of upland soils rich in organic matter is to be deficient in lime, while those of the lowlands are better and often richly supplied.

### VEGETATION TYPICAL OF NATURE OF SOIL.

As was noted in an earlier paragraph, the character of the soil, and especially its richness in lime, is often indicated by the nature of the vegetation growing upon it when in its virgin state. Thus, Hilgard[‡] notes that on the long-leaf pine bottom and hummock lands of Mississippi, with 0.05 to 0.4 per cent. of lime, where water stands in the undrained sub-soil, the ink or gall-berry, wax-myrtle and similar plants prevail, but disappear as the calcareous regions on each side are approached.

Heinrich[§] states that lime is certainly not lacking when the hedge-vetch, birds'-tare, chickling-vetch and red or other clovers form the natural vegetation, or when the oak, birch and locust flourish nearby, but that a deficiency of lime is to be suspected when there is a large quantity of sorrel (*Rumex acetosella*) or *Chrysanthemum segatum*, though no importance is to be attached to the presence of single individuals of these species for the reason that sorrel has been observed growing in marl pits, and in culture pots whose soil contained as much as 1 per cent. of lime. This author states that but few plants are really injuriously affected by lime and says that Uffelmann's supposition* that hearts-ease, quick-grass and chamomile disappear after a liming, is not credible.

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[*] X Census of the United States, 5, 81.

[†] Chem. Zeitung, 1895, No. 95.

[‡] X Census, 5, 267.

[§] Mergel u. Mergeln, 20-21.

A. Bernard† mentions the sand or maritime pine, the chlorotic varieties of the grape, the broom, digitalis and the chestnut as plants preferring non-calcareous soil. Speaking of the latter in particular, he urges that where the chestnut flourishes, the soil will be found poor in lime, even though the geological formation from which it is derived ordinarily yields a calcareous soil. Thus, examining the soil about the roots of a chestnut growing in a calcareous woodland of Ardéche, France, he found from traces up to only 0.6 per cent. of lime.

The laurel and the winter-green may also be mentioned as plants preferring non-calcareous soils.

Wheeler, Hartwell and Tucker‡ mention, as characteristic of the vegetation of certain acid upland soils of Rhode Island, birds-foot violet (*Viola pedata*, L.), wild or beard grass (*Andropogon scoparius*, Mx.), species of St. John's wort (*Hypericum*), common or soft rush (*Juncus effusus*, L.), wood rush (*Luzula campestris*, D. C.), and several mosses; while common sorrel (*Rumex acetosella*, L.), appears as soon as cultivation is begun.

## EFFECTIVE AMOUNT OF LIME IN SOIL.

The quantities of acid-soluble lime in the soil that are requisite to bring about the above noted differences in the kind and manner of growth of plants must vary both with the texture of the soil, as noted earlier, and with the quantities of acid-forming mineral and organic substances that are present. It is not, therefore, surprising that various investigators differ in opinions derived from observations upon different sets of soils. Thus Lloyd,§ states that, with rare exceptions, soils containing 2 per cent. of lime will not require liming; that soils containing 0.5 to 2 per cent. are usually benefitted by liming, and that it is indispensable to the profitable farming of soils containing less than 0.5 per cent. of lime.

Hilgard|| says that to manifest itself unequivocally in the tree growth, lime should not fall much below 0.1 per cent. in the lightest

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*Mergel u. Mergeln, 1893, 23.

†Le Calcaire, 268.

‡Report R. I. Agr. Exp. Station, 1895, 240.

§Science of Agriculture, 1884, 111.

||*Op.cit*., p. 76.

sandy soil, 0.25 in clay loams, or 0.5 in heavy clays, and may advantageously rise to 1 or even 2 per cent.; beyond this, it does not affect the soil favorably except in its physical characters. This writer[*] has observed that on sandy lands containing 0.04 to 0.13 per cent. of lime, having a depth of eight inches of surface soil, the long-leaf pine which grows naturally upon it is, upon the application of lime, supplanted by a growth of oaks.

R. Heinrich[†] claims that a good soil should contain at least 0.2 to 0.3 per cent. of lime and that liming is certainly required when the proportion falls to 0.1 per cent., and, in case of a heavy soil, it is needful before the amount has been reduced to 0.1 per cent.; when 0.15 per cent. is present, liming does not lead to an increased growth of rye, oats or potatoes, and when 0.3 per cent. is present, liming or marling is without beneficial result. The same investigator, in an earlier portion of his memoir, relates the result of experiments in the culture of various plants in soils to which different proportions of lime have been added; he concludes that:

| | Lime (CaO) in soil. (Per cent.) |
|---|---|
| Lupine grow well with, ............................ | 0.03 to 0.05 |
| Potatoes and rye yield good crops, under good tillage, with as little as, ................................ | 0.05 |
| Peas and vetches die with less than, .................. but do quite well with this proportion. | 0.10 |
| Red clover grows quite well with, .................. but dies with less than 0.1 per cent. and does best with 0.2 or more. | 0.1 to 0.12 |

### LOSS OF LIME BY CROPPING.

A number of calculations have been made to show the outgo of lime in farm products. Thus King,[‡] assuming a three-course rotation of corn, clover and oats to be followed for one hundred years, each with a total product of two tons per acre per annum, the hay and straw being returned to the soil, but the grain, or its equivalent being sold, finds that the hay and straw would contain 3,102 lbs. of lime, and the grain only 86 lbs., so that with an average of 1.88 tons of lime in the surface foot of soil, this alone would supply the needed lime for over 4,000 years, were there no other loss, without the aid of the lime present in the subsoil, which is more or less drawn upon by the roots of the crops.

Or, assuming a four-course rotation of corn, oats, wheat and mixed clover and timothy, producing average crops of the quantities mentioned in an earlier table (pages 54-55), assuming that all the wheat, half the oats, one-third of the corn and one-fourth of the hay were sold, the remainder of the crops being fed upon the farm; that one cow were kept for each two acres under cultivation, yielding 7,000 lbs. of milk sold off the farm each year and that for each cow there were bought 750 lbs. of cotton-seed meal and 1,500 lbs. of bran each year, the outgo would be, for each acre:

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[*] *Ib.* p. 284.

[†] Mergel u. Mergeln, p. 20.

[‡] The Soil, 102-104.

| | | Lime (Lbs.) |
|---|---|---|
| In wheat (6¼ bushels), | 0.22 | |
| In oats (6¼ bushels), | 0.20 | |
| In corn (4 1-6 bushels), | 0.07 | |
| In hay (220 lbs.), | 2.98 | |
| In milk (3,500 lbs., at 2 lbs. of lime per 1,000 lbs. milk), | 7.00 | |
| | | 10.47 |
| The income would be: | | |
| In 375 lbs. cotton-seed meal, | 0.68 | |
| In 750 lbs. wheat bran, | 1.27 | |
| | | 1.95 |
| Net annual outgo by cropping, | | 8.52 |

LIME ADDED IN FERTILIZERS.

On the other hand, the manurial substances brought upon the farm for the purpose of supplying nitrogen, phosphoric acid, potash and other substances, commonly contain also considerable quantities of lime.

Thus, in a ton of the following substances lime is contained in the quantities and states of combination indicated:

TABLE V—Amounts of Lime in Various Fertilizers.

| Substance. | Lime compound. | Pounds of lime. |
|---|---|---|
| Ashes (lime kiln), | Caustic lime and carbonate, | 970 |
| Ashes, wood, leached, | Carbonate and phosphate, | 560 |
| Ashes, wood, unleached, | Carbonate and phosphate, | 680 |
| Bone ash, | Phosphate, | 900 |
| Bone meal, | Phosphate. | 540 |
| Cottonseed hull ashes, | Carbonate and phosphate, | 190 |
| Gas lime, | Carbonate and sulfate, | 560 |
| Kainit, | Chlorid and sulfate, | 28 |
| Kieserit, | Chlorid and sulfate, | 56 |
| Marls, | Carbonate and phosphate, | 0-900 |
| Land plaster, Cayuga, | Sulfate and carbonate, | 800-850 |
| Land plaster, Nova Scotia, | Sulfate and carbonate, | 820 |
| South Carolina rock, ground, | Phosphate and carbonate, | 840 |
| South Carolina rock, dissolved, | Phosphate and sulfate, | 420(about) |
| Tannery ashes, | Carbonate and phosphate, | 680 |
| Tobacco stalks, | Nitrate, malate, etc., | 44 |
| Tobacco stems, | Nitrate, malate, etc., | 84 |
| Thomas slag phosphate, | Phosphate and oxid, | 970 |

With every pound of phosphoric acid applied in the ordinary forms of commercial fertilizer, the presence of at least 1¼ lbs. of lime is assured.

From these facts it is clear that in an application of 200 lbs. of dissolved South Carolina rock, fully 40 lbs. of lime is added to the soil, an amount several times greater than that removed in a single year by the crops sold off from the acre.

## VI. INFLUENCES OF LIMING UPON SOILS AND THE VALUE OF MAGNESIAN LIMES.

Having noted the quantities and conditions in which lime occurs naturally in the soil, and the ways in which it is lost or increased by the processes of cropping and chemical manuring, it remains to consider the changes wrought in the soil by the application of lime.

### CLASSES OF EFFECTS OF LIMING.

Numerous observations and investigations have shown that the direct and indirect results of liming are quite numerous and complex, instead of being few and simple. The various results may, however, be grouped as those which affect:

A. The mechanical condition of the soil;
B. Its chemical composition particularly as regards
    1. The kind and proportion of available plant food it contains.
    2. The presence of substances injurious to plant life.
C. The biological characters of the soil; i. e., the nature and vigor of the organisms living in it and of the plants growing upon it.

These different effects of liming will be discussed in the following paragraphs, free use being made of the numerous observations and experiments made elsewhere upon the subject; but the effects of lime upon a number of Pennsylvania soils that have shown in practice very marked benefits from liming, will be presented so far as they are indicated by the results of careful laboratory investigations made by the writer, with the aid of his assistants in the Chemical Laboratory of The Pennsylvania State College Experiment Station.

### SUPPOSED INJURIOUS EFFECTS FROM MAGNESIAN LIMES.

It was thought desirable to study, at the same time, the effect of caustic magnesia upon these soils, for the reasons that a very large proportion of Pennsylvania limes are magnesian and that the general opinion of agricultural writers has been that highly magnesian limes may not only be of little use, but may even prove positively injurious to the crops. Thus, Lloyd[*] states that lime is the only material of value in burnt lime and applies the adjective "bad" to a lime containing 60 per cent. of lime and 30 per cent. of magnesia. Low[†] says of the magnesian limestone of England: "If applied, after being calcined, in the same quantity as other limes, it produces a temporary sterility, burning, as it were, the soil; hence, it is termed hot lime and is applied in much smaller quantity than other kinds of lime." This action he attributes, after Sir Humphrey Davy, to the longer period of causticity commonly supposed to occur with magnesia. In the form of carbonate, he says, "magnesia seems to exercise a highly favorable action; and magnesian limestone may perhaps be regarded as the most valuable of any, since a smaller quantity of it suffices for the ends proposed. No other limestone is so efficient in the case of peaty soils, and it is probable that the superiority observed in the case of the limestone of the coal formation over that of the pure chalk is due to the presence of this earth."

Prof. Geo. H. Cook,[‡] late geologist of the State of New Jersey, and Director of the New Jersey Experiment Stations, says, in speaking of limes: "It is doubtful whether magnesia has any fertilizing properties, and it is thought by many that it is a loss to buy and handle magnesian limes."

P. P. Dehérain,[§] speaking of hydraulic limes in general rather than of magnesian limes simply, says they will, if spread upon the soil without previous complete exposure to the air, form a hard layer upon the soil during the first rain and become injurious rather than useful.

J. Boehm's[||] observation that carbonate of magnesia is unable to take the place of lime in promoting healthy germination but is, instead, positively poisonous, has already been noted.

R. Heinrich,[**] having observed injury resulting from the effect of calcium carbonate upon the growth of the lupin, states that magnesium carbonate is far more injurious, the presence of 0.5 per cent. being sufficient to entirely prevent the growth of the plant. The same writer[††] says: "It is suspected that applied in considerable quantity, so that, especially, the magnesia exceeds the amount of lime in the soil, it is as deadly to some plants as lime carbonate is to lupins. Different plants show different sensitiveness to the magnesia content of the soil. Most dolomitic rocks contain far more lime than magnesia; no immediate injury, therefore, results from their use, but because lime is more freely dissolved out of the surface soil than magnesia is, the injurious effect may be seen later when the magnesia comes to be in excess. The injury from caustic magnesia is clearly established, but further investigation is needed regarding the effect of the carbonate."

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[*] Science of Agriculture, 113.

[†] Practical Agriculture (4th ed., 1843), 88.

[‡] N. J. Agr. Exp. Station, 2d Ann. Rep., 31.

[§] Chimie agricole, 530.

[||] Ann. agronomiques, 1, 470.

[**] Mergel u. Mergeln, 63.

[††] *Ib.* p. 81.

The subject is quite fully discussed by Storer,[*] who notes that it was early observed by English chemists that certain limestones which had sometimes been found in practice to injure crops, contained magnesia, and that Tennant, on applying calcined magnesia to various soils with different crops, found that his plants either died, were unhealthy or vegetated very imperfectly; also, that Knop found, in growing plants by water culture (i. e., in very dilute solutions of plant foods), that magnesium salts are distinctly harmful unless accompanied by abundance of lime, potash or ammonia salts; by themselves, the magnesium salts caused peculiar malformations of the plant roots, followed shortly by the death of the plants.

Storer notes, on the other hand, that Sir Humphry Davy found that the very magnesian limestones to which objection was made, gave very beneficial results on certain soils and that magnesia, though injurious when present in caustic condition in considerable quantity in ordinary soils, may be beneficial when mixed with peat or when present as carbonate. He also notes Stöckhardt found, in the limestones producing the best results and most enduring upon the lowlands of Saxony, as much as 40 per cent. of magnesia. The suggestion is made that the readier solubility of magnesium carbonate in the carbonated soil-water may give magnesian limes real superiority over pure limes as ameliorants of heavy land.

Viala and Ravaz[†] have observed that dolomitic soils are not nearly as injurious in the production of chlorosis of the vine as are more purely calcareous lands. Bernard suggests that this is due to the somewhat greater resistance to decomposition offered by magnesium carbonate.

O. Kellner[‡] urges that magnesia is useful, and poisoning of the plant by it is the result simply of using it in too large quantities.

## FUNCTIONS OF MAGNESIUM IN PLANTS.

In support of this opinion it may be summarily noted in this connection, as established by numerous experiments by the methods of water-culture and of sand-culture, that magnesium is absolutely indispensable to the growth of plants to full maturity. While all its functions in the plant are not known, it is certainly able to neutralize acids as lime does, though it does not form crystallizable compounds so easily thrown out of circulation as calcium carbonate or calcium oxalate. Like lime, it is present in aleurone grains with albuminoid materials and forms alkaline phosphates which may aid in the movement of albuminoids from one part of the plant to another. Its most clearly established function, however, is its necessary connection with the formation of chlorophyll, the green coloring matter through whose agency, under the action of sunlight, the plant is enabled to fix the carbonic acid of the air in its leaves in the form of sugar, starch or oil. Von Raumer[*] found that in the scarlet runner, when deprived of magnesium, the uppermost joints soon ceased to lengthen, became exceptionally thick and hard and showed only the faintest green tint, the color being almost white. Hoppe-Seyler[†] found in the pure crystallized chlorophyllan obtained from grass, 0.34 per cent. of magnesia; and chlorophyllan appears to be closely related to the ordinary chlorophyll.

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[*] Agriculture, 4th ed., 1897, II, 135-7.

[†] Bernard, Le Calcaire, 63.

[‡] American Fertilizer, 6, 245

### USE OF MAGNESIUM SULFATE AS A FERTILIZER.

A second fact in support of this opinion is the good result occasionally attending the use as a fertilizer of magnesium sulfate (Epsom salts) in the form of the Stassfurt salts, kieserit and krugit.

## PENNSYLVANIA EXPERIMENTS.

### SOILS EXPERIMENTED UPON.

The soils used in the experiments hereafter described were carefully selected to represent a large variety of the soils for which a large return from liming was claimed by various correspondents. The source, nature, response to liming and method of sampling of the several soils are stated below.

I. *Ironstone soil*, from the Spring-and-Meadow Farm, Washington Township, York County, sampled by Mr. L. W. Lighty, East Berlin, Adams County, Pa. This soil formation lies between strips of blue shale, outside of which are found red shale and red sandstone; the ironstone soil is about three-fourths of a mile wide and extends from the Susquehanna opposite Marietta, bearing south of west, passing south of Gettysburg. The soil is uneven in formation; 10 per cent. of it is a whitish clay of very fine texture, runny when wet, but powdery, not cloddy, when dry; 5 per cent. is a tough, heavy, cold clay, mixed with a small proportion of coarse sand; this soil dries very slowly and bakes to clods; 5 per cent. is pure, rather coarse sand mixed with flint and granite, but 80 per cent. is a very fine sand, mixed with less clay, and it becomes sticky and smeary when wet and dries slowly; when handled properly in a dry condition, it works very nicely; washes and gullies when on an exposed slope. In general, the soil is a fine, grayish-yellow sand. It is very deep, sometimes as much as forty feet. Soil taken from far below the surface and spread upon the ground, supports at once a very rank, vigorous vegetation, and is rarely bare, weeds and briers growing rapidly in the absence of crops. The soil bears drought very well, and is a hard, rough soil, but responds well to treatment. All crops and trees grow well upon it.

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[*] Versuchs-Stationen, 20, 263-273.

[†] Quoted by Johnson, How Crops Grow (1890), 125.

The sample was taken from a tract of four acres, having a surface soil one foot deep, with a sub-soil similar, but sharper and full of boulders. The tract was rolling upland, rather damp, had been long under cultivation in a rotation of corn, wheat and clover; its production is about 15 bushels of wheat and 60 bushels of ear corn; its plow depth is about 10 inches. Liming alone is not so noticeably useful as its application in connection with clover sod or manure. The soil is naturally well supplied with humus and rarely becomes deficient therein. When lime is applied to this soil, 20 to 50 bushels makes no easily apparent change in its condition; if more than 50 bushels be added, the soil becomes mortar-like and hard to handle. After liming, the retentiveness for moisture appears to be increased. The particular tract sampled had not been limed for at least forty years, and was in corn-stubble when the sample was taken; sub-samples were taken of the surface soil at twelve different points, carefully mixed by shoveling over and passed through a one-half inch screen; 3 per cent., consisting of roots and small stones, failed to pass the screen. The combined samples amounted to several barrelfuls.

II. *Black slate soil*, from Hopewell Township, Cumberland County, Pa., about five miles north of Shippensburg; sampled by Hon. S. M. Wherry, of Shippensburg. This soil is light, easily tilled, easily affected by drought, but yielding well in wet seasons; liable to wash. The soil grows hickory, all kinds of oaks, some pines, fall-grass, rag-weed and all forms of briars, and is especially good for wheat. The surface soil is about twelve inches deep, although the plow-depth is commonly only six to eight inches. The sub-soil is hard, black slate or red shale. Lime seems more beneficial upon this than upon most soils in the locality. The tract of ten acres from which the sample was taken had never been limed, but was an old soil under a rotation of corn, oats, wheat and grass. Sub-samples were taken from eight points in the tract, to a total weight of 1,000 to 1,200 pounds; after careful mixing the soil was screened and about one-half of the entire amount—composed of sod, roots and large pieces of slate —failed to pass a half-inch mesh screen.

III. *Red shale* from Lykens Valley, Dauphin County, Pa., sampled by Mr. John Moyer, Gratz, Pa. This soil is a dry, sloping upland, with surface soil of fourteen to twenty inches, and a plow-depth of six or seven inches, and with a red gravel sub-soil. The soil tends to bake and solidify on drying so as to greatly injure any crop growing upon the land. The golden rod and plantain are the most conspicous weeds, and wheat grows better than other crops, but the soil is not naturally strong; the fertility after the use of lime, with manure, is greatly improved, and the soil is kept much lighter and more porous. The twenty-acre tract from which the sample was taken had not been limed for at least twenty years, and, before that, only infrequently and at a rate of not more than fifty bushels per acre. The land had been under cultivation for a long time, and when sampled was in corn; ten sub-samples were taken at different points to a total amount of four bushels; these were well mixed and put through a one-fourth inch screen; stones and roots to the amount of one-fourth of the original soil were separated.

*IV. Limestone clay* from the eastern slope of the limestone strata running through Morrison's Cove, in South Waverly Township, Bedford County, one mile from Loysburg Gap; sampled by Mr. J. S. Biddle, of Loysburg, Pa. The soil is a very heavy "limestone" clay, which cannot be worked wet and bakes on drying. Rag-weed, the wild cherry and apple and clover grow vigorously and corn does very well. The soil is about six to eight inches deep, and the sub-soil is heavy clay several feet deep. Lime loosens it. The tract of two acres from which the sample was taken was dry, sloping upland that had been under cultivation for over fifty years and had never been limed; sub-samples were taken at twelve places and the mixed soil passed through a one-quarter inch screen, through which one-third of the weight refused to pass, composed of stone, roots, etc.

*V. Glacial loam* from Scrubgrass Township, Venango County, sampled by Mr. Ed. Anderson, of Big Bend, Pa. This soil is loose, with a gravelly sub-soil, containing a little clay; wet weather does not injuriously affect it. The prevailing forest growth is chestnut, and produces about fifteen bushels of wheat to the acre. The sample was taken from an upland tract of twenty-five acres, part upland level, part slope; sub-samples were taken at six points to a total weight of 1,000 pounds. Of this, one-third, composed of small stone, grass roots, etc., failed to pass a one-quarter inch screen. This land had been in wheat four years before and in grass since then; the soil was old and had never been limed.

*VI. Muck* soil from the "sand barrens" of Centre County, a narrow strip one-half to several miles in width, extending for twenty-five to thirty miles through Nittany Valley, and containing many small hollows, more or less filled with muck and sandy wash. The sample was taken at a spot about two and one-half miles from the State College, by Mr. W. S. Sweetser, Assistant Chemist of the Experiment Station; the hollow from which it was taken was 150 to 200 square feet in area, with a surface of muck five to six inches deep, and with a sub-soil of almost pure sand. The vegetation upon the surrounding tract was of pine, chestnut and oak. The soil was virgin, of course, and ten samples, amounting to about a barrel, were taken. Of this, one-tenth only was too coarse to pass a one-quarter inch mesh, the coarse material being composed solely of sticks and roots.

*VII. Limestone clay* soil from Nittany Valley, Centre County, on the farm of Mr. A. Markle, State College, Pa., representing well the large soil areas forming the floor of central Pennsylvania valleys, the soil being formed from the Lower Silurian rocks. This soil often responds very well to liming, the texture being made more porous, and crop yields considerably higher. The characteristic tree is the oak, and rag-weed the most abundant mid-summer weed. The sample was taken by Mr. W. S. Sweetser, from a field of one acre area that had never been limed; it was in corn at the time, forming part of the ordinary four-course rotation. The situation was upland, the soil well drained naturally, with surface soil of ten inches depth, and a usual plow-depth of seven to eight inches. The sub-samples were taken from eleven points to the amount of a barrel. Of this, 4 per cent. only, composed of small stones with a few roots, was too coarse to pass a one-quarter inch mesh.

VIII. From the farm of Mr. Mitchell Bachle, Blanchard, Pa., *Creek bottom loam*, sampled by Mr. C. W. Norris, Assistant Chemist of the Experiment Station. Soil was of rather light, sandy texture, and of light color; the surface of the ground sloped a little toward the southeast, but was otherwise quite level. The land was cropped with clover, had been long cultivated and never limed, nor has it been manured for seven or eight years. The plow depth is 10 inches. Land responds well to liming. The tract sampled lay near the creek, was of two acres area, and was sampled in 10 places. Of the combined sub-samples, little more than 2 per cent., consisting of small stones and roots, failed to pass a screen of one-quarter inch mesh.

*IX. Red shale* soil from the farm of Mr. David Mapes, about two miles west of Beech Creek, Clinton County. The soil is especially productive of clover and the plaintain was the most conspicuous weed upon the tract sampled. The effect of liming is to loosen the soil and greatly improve the yield. The tract was sloping upland, dry, with a surface soil ten inches deep, and a hard red-shale sub-soil; the plow-depth was eight inches. The field had been in cultivation for twenty years in the ordinary four-course rotation and is not known to have been limed. Over an area of two to three acres, sub-samples were taken at thirteen places to the amount of 700 pounds. Of this, 27 per cent., composed of small, flat stones, failed to pass a one-quarter inch mesh.

## CHEMICAL ANALYSIS.

Of each of the samples thus collected, a large portion was carefully air-dried in a drying-closet, the sample allowed to remain exposed for some time to the air of the laboratory and then carefully sifted through a one-half millimeter sieve to remove gravel, roots, etc. Of these various samples the following proportions were able to pass the sieve, the figures for Samples VI and VII having failed to be preserved:

| | Per cent. |
|---|---|
| I, | 78.4 |
| II, | 50.0 |
| III, | 75.1 |
| IV, | 77.1 |
| V, | 88.6 |
| VIII, | 89.7 |
| IX, | 79.1 |

In preparing a solution of these soils for the purpose of determining in part the materials capable of solution in hydrochloric acid of 1.115 specific gravity—the solvent customarily employed in soil analyses and supposed to indicate the kind and amount of material capable of being taken up by plants sooner or later as the land is cropped—the following method was used: Ten grammes of the air-dry soil were introduced into a small flask, 100 c. c. of the acid added, the flask connected with a reflux condenser and digested for ten hours on a water-bath at the temperature of boiling water. The flask was cooled, the liquid filtered off from the undissolved residue, the filtrate evaporated to dryness. The soluble silica present in the original acid solution having been thus rendered insoluble, the other substances were redissolved in a few drops of hydrochloric acid and hot water and the solution filtered. The filtrate was made up to 500 c. c., and various portions of it used for determining several of the soil constituents by the official methods of the Association of Official Agricultural Chemists of the United States.

*Lime and Magnesium Carbonates in the Soils.*

In the following table are given the percentages of hygroscopic moisture, lime, magnesia and carbonic acid present in the several soils; also, the proportions of the lime present in the form of carbonate; these determinations were made by Mr. C. W. Norris, Assistant Chemist; in no case was the carbonic acid liberated on warming the soil with dilute acid, sufficient to combine with all the lime present, much less with the magnesia also.

**TABLE VI—Lime, Magnesia and Carbonic Acid in Soils. (Per Cent.)**

| Soil. | Hygroscopic moisture. | Lime. | Magnesia. | Carbonic acid. | Proportion of lime combined as carbonate. |
|---|---|---|---|---|---|
| I, | 2.37 | 0.83 | 0.75 | 0.034 | 5.1 |
| II, | 2.00 | 0.24 | 0.71 | 0.039 | 20.4 |
| III, | 1.89 | 0.25 | 0.43 | 0.035 | 17.6 |
| IV, | 1.64 | 0.29 | 0.44 | 0.044 | 19.0 |
| V, | 1.96 | 0.08 | 0.19 | 0.025 | 38,8 |
| VI, | 4.85 | 0.11 | 0.10 | 0.046 | 53.6 |
| VII, | 1.36 | 0.26 | 0.35 | 0.039 | 19.2 |
| VIII, | 1.49 | 0.29 | 0.45 | 0.030 | 13.2 |
| IX, | 1.73 | 0.28 | 0.69 | 0.048 | 21.8 |

The variations in hygroscopic moisture are evidently too slight to introduce any material error in conclusions drawn from a direct comparison of the foregoing figures.

It is interesting to observe that only in the case of the glacial loam, No. V, and of the muck soil, No. VI, are the proportions of lime less than 0.2 per cent., the amount considered sufficient for the food supply of agricultural plants. Yet, except in case of the ironstone soil, the proportions are not far above this requisite proportion.

In every instance except those of No. I and No. VI, the ironstone and muck soils respectively, the percentage of magnesia in the soil is appreciably greater than that of lime; and in the exceptional soils indicated the lime is barely more than equal to the magnesia.

Except in the muck soil, only a small part of the alkaline earths are present as carbonates;* in most instances, not more than 20 per cent. of the lime is so combined, and in the ironstone soil only 5 per cent. Doubtless a very considerable part of that dissolved is present in the soils in the form of silicates.

*Ratio of Lime to Magnesia.*

Concerning the proportions which the magnesia bears to the lime in these soils, it may be further remarked that the excess of magnesia here observed is not at all unusual; the mean percentage of lime in 466 non-calcareous soils from humid regions that were analyzed by Hilgard, was 0.108 per cent., while that of magnesia was 0.225 per cent.; in 313 soils from arid regions, the average lime content was 1.362 per cent.; that of magnesia, 1.411 per cent.

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*Much care was used in determining the carbonic acid: 20 grammes of the fine, air-dry soil was introduced into a small flask, covered with freshly boiled water and thoroughly moistened by agitation. The flask was then connected with such absorption apparatus that the air entering the flask is free from carbonic acid, while any of this gas liberated from the soil is absorbed, after the air has been dried, in a special weighed portion of the apparatus, from whose increased weight the quantity of carbonic acid is ascertained. Forty c.c. of concentrated hydrochloric acid was then introduced into the flask, its contents heated to boiling and the air drawn through the apparatus for 15 minutes as the flask cooled.

In view of these facts, it is unsafe to conclude that an excess of magnesia soluble in hydrochloric acid of 1.115 specific gravity is indicative of a condition of the soil whereby pronounced injury must result to crops growing upon it. It is more probable that the supposed injurious action must be attributed to the presence in excess of some particular magnesian compound or compounds, rather than of magnesian compounds in general.

The mere fact that the composition of large agricultural areas represented by the above analyses shows an average preponderance of magnesia over lime, does not, of course, preclude the possibility that a reverse relation of the acid soluble portion of these two soil components might prove more advantageous to plants grown under the artificial conditions of agriculture. There is, however, no warrant in existing knowledge upon the subject for concluding that any part of the benefits observed to result from the application of lime to the several soils experimented upon, arises from a change in the ratio between the magnesia and lime present. It is noteworthy, however, that where the differences in percentage between the two are only slight, no unusual application of lime would be required to overcome it; thus, for each 0.1 per cent. of excess of magnesia over lime, an application of little more than a ton of pure lime per acre would equalize the amounts of these substances in the surface soil taken to a depth of eight inches; whereas, applications of ten tons to the acre are not very infrequent.

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## DETAILED PLAN OF EXPERIMENTS.

Owing to the difficulty of detecting by analysis minor changes in the composition of soils, a maximum application was determined upon. Two hundred bushels of the heavier stone lime would weigh about 18,000 lbs.; assuming the dry surface soil to weigh 3,600,000 lbs. per acre, taken to the depth of a foot, such an application would correspond to 1 lb. of lime to each 200 lbs. of soil. As the mechanical mixture of the soil and lime is not perfect under the usual conditions of liming, it doubtless happens quite often that the immediate influence of the lime applied is limited to a zone of three or four inches depth. Under laboratory conditions, the admixture is much more perfect, so that the above proportion need not be considered as excessive in such degree as to impair the value of any results obtained.

Both the lime and magnesia were chemically pure, and perfectly caustic; only freshly ignited materials, cooled under conditions that precluded air-slaking, were used.

As it was considered probable that the chief effects would be those resulting from chemical reactions produced by the lime and magnesia respectively, the latter was not employed in quantity equal to the lime, but in such amount as would be chemically equivalent to it, viz: 40 parts of magnesia to 56 parts of lime.

The quantity of soil used was 2,000 grammes.

Three treatments were given to as many portions of the several soils.

A. Preservation in a moist condition without any admixture.

B. Mixture with 10 grammes of lime, and preservation in a moist condition.

C. Mixture with 7.14 grammes of magnesia, and preservation in a moist condition.

The lime and magnesia were thoroughly mixed with the soils, both being in dry condition.

The dry soils subjected to the several treatments were then introduced into large bottles, so covered as to protect their contents from the ready entrance of dust, insects, etc., but without preventing a constant change of the air in the bottles. The soils were then carefully moistened without stirring, placed in a basement room and kept there for ten months. During the first three months water was added in small quantities, to maintain a uniform condition of moistness so far as the eye could determine. At the close of the ten-month period, the soils were air-dried, again sifted through a one-half mm, sieve, as at first, and preserved in sealed jars pending analysis.

## MECHANICAL EFFECTS OF LIMING.

### *Influence Upon Clay Soils to Increase Porosity.*

It is a matter of almost universal comment that the application of lime to a "runny" or heavy clay results in a marked increase in the porosity, lightness and crumbly character which are essential to a soil fit for the highest tillage. Indeed, so marked is the influence of lime upon such soils that, in some localities, it is asserted that only upon heavy clay land is lime ever beneficial. To reach an understanding of this effect of lime, it is needful to consider the essential differences between the heavy clay and the lighter soils. The terms "heavy" and "light," as used in this connection, do not refer to weight, because a cubic foot of dry sand weighs about 110 lbs., while a cubic foot of clay, taken from "heavy" land, often weighs only about 80 lbs. Reference is had instead to the draught required for their tillage, the adhesiveness and strong coherence of the clays, greatly increasing the power necessary to draw the plow through them as contrasted with sandy soils.

*Mechanical Character of Clay Soils.*

These differences are due chiefly to the texture of the soil or, in other words, to its mechanical structure. All soils are composed of more or less finely sub-divided minerals resulting from the weathering of the rock from which the soils were derived, with more or less "humus," or decayed vegetable matter admixed. A separation of the fine and coarse particles in various soils shows them to be vastly different in the proportions of the particles of various diameters which they contain. The following data obtained by Whitney,* in examination of the coarse "pine barrens" and heavy Helderberg limestone clay soils of Maryland, will serve to illustrate the mechanical differences between the two types of soil (all material coarser than 2 mm. diam. having been first removed by sifting):

| | Pine barrens soil. | Heldeberg limestone soil. |
|---|---|---|
| Number of grains per gramme of soil (millions), | 1,692 | 19,638 |
| Surface area of the particles in 1 gramme of soil (in centimeters), | 496 | 4,575 |
| Empty space in the dry soils (per cent), volume, | 40 | 65 |
| Water content when saturated (per cent.), by weight, | 20.1 | 41.2 |

It is clear, therefore, that the number of grains in a given weight of clay soil is very much greater than in the same amount of a sandy soil, and, consequently, that the average diameters of the clay particles must be much less than those of the sand grains. It is further clear that, since the density of the minerals composing sand and clay are much the same, a dry clay soil weighing less than a sandy one, the arrangement of particles in the clay must be such as to leave more empty space, and direct examinations of the soils in the field show this to be true. A clay soil will, when saturated, hold more water than a sand. Owing to the fineness of pores in a clay soil, water will be lifted higher in it by capillary action, will be pulled out of or through it more slowly by the influence of gravity and, when the soil is dry, will distribute more slowly through it. It is, therefore, characteristic of clay soils to be more moist than sandy soils in damp weather, to dry more slowly in spring time, to swell on becoming moist after a dry season, to heave on freezing by expansion of the water contained and to bake into a hard mass on drying. In such compact soils, the roots of plants penetrate with difficulty, the roots are broken by the heaving during the winter's frost and plants suffer from excessive wetness and coolness of the soil in spring time and from excessive drought in summer.

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*U. S. Weather Bureau, Bull. 4.

Furthermore, if such soils are trampled, pressed by the plow share or kneaded in any way, the arrangement of the particles is changed and the clay is said to be "puddled." In such condition water, even under high pressure, scarcely passes through it; upon drying, it bakes in the form of hard clods; it is readily gullied by running water, making the streams highly muddy. The tillage of such land requires the greatest care.

The plasticity that is characteristic of clay soils is by some attributed to a gummy, or "colloidal," cementing substance, probably a silicate of alumina; by others it is urged that the very fineness of the particles is in itself sufficient to account for this quality. There is some evidence that both are in part correct.

### *Flocculation of Clays.*

When the extremely fine silt or mud from certain clays is suspended in rain water, it often settles out only very slowly. Prof. Wm. H. Brewer, of Yale University, in a private communication, informed the writer that a sample taken by him from the muddy waters of the Missouri river and placed on a shelf, where it was free from agitation, failed to settle clear even after six months had elapsed.

If, however, certain saline solutions are admixed with the muddy water, the precipitation of the silt is greatly hastened. This is accounted for upon the supposition that several of the fine particles are made under the influence of these solutions, to cohere, in light flocks, whereby their surface is diminished and they settle out from the liquid more readily. Thus, when the muddy waters of the Mississippi encounter the waters of the Gulf, the salts in the latter bring about the "flocculation," as this change in condition is termed, and the silt deposits to form the great delta which is ever pushing out into the Gulf.

On examining the flocculating power of various substances, Schlösing[*] found that quick-lime and the various salts of lime were the most active flocculants, magnesium salts nearly as effective, potassium salts weaker and the salts of sodium and ammonium still weaker. In some cases, two parts of lime in the form of chlorid, nitrate or sulfate, caused immediate flocculation in 10,000 parts of turbid, clayey liquid.

Hilgard has repeated Schlösing's experiments with like results.

The action of these flocculants upon a "runny" clay soil likewise results in its granulation or flocculation. If, however, the flocculant

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[*] *Cf.* Storer, Agriculture, 4th ed., Vol. II, p. 144.

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be removed by leaching, the "runny" character of the clay reappears. To show this action, Hilgard suggests the following experiment: Work a portion of tough clay into a plastic mass with soft water; on the one hand, mix one part of caustic lime with 200 of the clay before working into a paste with water; on drying, the former portion becomes of almost stony hardness, the latter crumbles readily at the touch.

*Theories of Flocculation.*

The cause of this action is not fully understood. Schlösing found that in washing the soluble materials from soils by water, silt was held back when a current of carbonic acid gas was passed through the soil during the washing; from this fact it has been inferred that the acid carbonate of lime is the active flocculant. Hilgard* also observed that the destruction of the causticity of the lime in a magma of limed clay by causing a stream of carbonic acid to bubble through it for twenty-four hours, did not at all restore the plasticity of the clay; hence, the flocculation does not necessarily require caustic lime. But the action of the neutral carbonate is much weaker.

Hilgard, Brewer and Barus,† proceeding upon the theory that the clay particles are, in part at least, in a gummy or colloidal condition, suggest that flocculation results from a dehydration of the clay under the action of the saline solutions. Whitney urges, however, that such an assumption is needless since the facts may be accounted for by the laws of surface tension; for, assuming two grains of clay to lie in contact with each other on the surface of a liquid, if the attraction of the liquid for the surfaces of the clay is greater than the attraction between the different portions of the liquid, the latter will rise between the particles and tend to separate them; if, on the other hand, the reverse is true, the clay particles would, when separated, tend to come together. The determinations made by this investigator‡ of the power of various flocculant solutions, as compared with water, to rise in a glass tube, shows, however, that the former rise higher and that their observed relations in this respect do not correspond with their flocculant activities as ascertained by Schlösing and Hilgard.

The observations of King§ do not, however, fully accord with Whitney's in respect to the influence of lime upon the capillary movement of water; for he found that the rate at which water passed upward through columns of coarse sand and away by evaporation, was decreased rather than increased by the addition of lime water, thus indicating for the latter a lower capillary power.

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*Storer. *Ib.*, p. 145.

†*Cf.* Whitney, Bull. 4, U. S. Weather Bureau, p. 21.

‡*Ib.* pp. 15 and 16.

§The Soil, pp. 177-8.

### *Duration of Effect.*

Whatever be the explanation, the fact remains that the "lightening" effect upon such soils resulting from liming is very marked and often lasts for years.

### *Influence Upon Water Movement.*

Pearsen[*] has noted the interesting fact that a clay soil which allowed a layer of water only five centimeters (two inches) deep to penetrate through it in no less time than twenty-nine days and nineteen hours, when mixed with 2.5 per cent. of lime, permitted the completion of the percolation in only seven hours.

In case of such a soil lying upon a steep slope, it is readily seen that one result of liming would be the readier percolation of the water through the body of the soil with a correspondingly lessened tendency to form rivulets upon the surface, which might wash it into gullies; nor would the percolation be accompanied by the removal of the finer particles of the soil.

### *Modifying Effect of the Lime Already in the Soils.*

Hollemann,[†] working upon stiff clays at Groningen, Holland, found their porosity improved by addition of lime in the form of carbonate, whenever the quantity of lime in the soil was less than 0.15 per cent.; but that no benefit was perceptible from its application when the soil contained as much as 0.5 per cent.

King[‡] observes that there appear to be some exceptions to the general rule that the presence of calcium carbonate ensures the friability of fine clays, from the fact that there are many clays, very impervious to water, plastic and adhesive, which are unfitted for use in making brick or pottery, because of the lime they contain, the amount sometimes reaching 5 per cent. As a possible explanation, this writer suggests that it may be that the lime, once in the impervious clay, could not be acted upon by the carbonic acid sufficiently to form enough acid carbonate of lime to effect the flocculation.

### *Injury from Liming Clays.*

It is, however, distinctly recognized that the too frequent and copious application of lime even to clay soils may eventually render them hard and compact, instead of friable and open. In this case, the cementing action of the calcium carbonate formed in the soil appears to more closely resemble that observed in the case of ordinary mortar.

A similar injury results from the application of large dressings of caustic lime upon a clay when it is in a wet condition. On very wet clays, draining should precede liming.

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[*] Chemical News, 1888, p. 53.

[†] Ldw. Vers.-Station, 41, 77.

[‡] The Soil, pp. 30-31.

### *Mechanical Effects Upon Light Soils.*

Observations upon the influence of lime upon the texture of light soils are more divergent in their conclusions. Many correspondents in this State affirm that the application to light soils makes the latter more retentive of moisture and that this is more true of shales and gravels containing considerable proportions of fine particles than it is of sharp sands or even of alluvial sand deposits. It is noted in particular that the liming of the blue slate uplands of Fulton and Bedford counties has so increased the retentiveness of the soil for moisture, that clover can be made to live through the summer, where, without liming, it dies from drought. These statements accord with experience elsewhere.

### *Experiments on the Influence of Lime and Magnesia Upon the Water Capacity and Hygroscopic Coefficient of Soils.*

Upon the several soils under treatment in the experiments conducted in my laboratory, no observations were made to determine the effect of the several treatments upon the rate at which water would percolate through them. But determinations were made by Mr. C. P. Beistle, Assistant Chemist, of the water-holding capacities and the hygroscopic coefficients, or power to absorb water vapor, of the several lots of soil. For the former determinations, the dry soils were weighed into tared glass funnels, upon uniform filter paper, and water was then added until the soils were saturated; when drops ceased to come through the funnel, the tops being covered to prevent evaporation, the funnels were weighed with their contents, and the quantity of water retained was thus ascertained.

For the latter determination, one portion of soil was taken for the estimation of water held under laboratory conditions; another portion was exposed for twenty-four hours upon an open watch-glass in a box so constructed that the air it contained should be saturated with water vapor.

The gain in weight due to the absorption of water, plus the weight of vapor already present, gives, when figured in percentage upon the basis of the dry soil, the hygroscopic coefficient.

TABLE VII—Moisture Relations of Soils.

| Soil. | Water-holding Capacity (Per cent.) | | | Hygroscopic Coefficient. (Per cent.) | | |
|---|---|---|---|---|---|---|
| | Blank. | Lime. | Magnesia. | Blank. | Lime. | Magnesia. |
| I. Ironstone, | 46.15 | 47.53 | 47.40 | 3.60 | 3.59 | 3.27 |
| II. Black slate, | 53.65 | 54.15 | 54.40 | 2.95 | 2.87 | 2.86 |
| III. Red shale clay, | 47.15 | 43.53 | 43.85 | 1.67 | 1.78 | 1.57 |
| IV. Limestone clay, | 49.03 | 51.53 | 47.15 | 1.80 | 1.84 | 1.53 |
| V. Glacial clay, | 48.78 | 47.53 | 50.40 | 1.69 | 1.85 | 1.69 |
| VI. Muck, | 77.89 | 82.53 | 79.40 | 4.68 | 4.94 | 5.23 |
| VII. Limestone clay, | 52.89 | 49.01 | 51.52 | 1.58 | 1.59 | 1.98 |
| VIII. Loam, | 49.98 | 47.11 | 50.39 | 2.37 | 2.44 | 2.39 |
| IX. Red shale, | 54.98 | 54.36 | 54.98 | 2.28 | 2.23 | 2.14 |

As regards the *water-holding capacity*, it is to be remarked that the range of difference exhibited by the several untreated soils is not large, viz: from about 46 to 78 per cent.; the muck soil in particular shows a strikingly low capacity; it is entirely possible that in the case of this soil, the porosity was impaired by the sifting through so fine a mesh. The influence of the liming upon the empty space and arrangement of particles is not clearly marked so far as it is indicated by the water-holding capacity of the soils; in four instances of varied character, the capacity seems to increase; in five, to diminish slightly; the magnesia exerted as marked an influence, but in samples IV, V and VII, its action was opposite to that of the lime. It is probable that, to exhibit the characteristic change, the conditions of after treatment of the soil have not been favorable. It is hoped to repeat the work under other conditions, but time has not permitted the repetition prior to the preparation of this report. Bearing upon the importance of these conditions, the old observations of Zengar[*] and Wilhelm[†] that the pulverization of soils consisting of porous particles such as lime-sinter or peat, to some extent destroys their porosity and power to retain liquid water, may be recalled.

As regards the *hygroscopic coefficient,* or power to take up moisture vapor, likewise, there is no clear indication that the lime or magnesia exercises any clearly marked influence, and the experiment must be repeated upon portions of soil not treated as those must be which are to be subjected to chemical analysis. Hilgard[‡] affirms, however, that this power to take up moisture vapor depends essentially upon one or more of four substances, *humus*, *ferric hydrate*, *clay* and *lime*, named in the order of their efficiency. "It varies," he says, "from 1.5 to 23 per cent. at 15 degrees Centigrade in a saturated atmosphere. A pure clay rarely exceeds 12 per cent.; ferruginous clays show 15 to 21 per cent.; some calcareous clays rise nearly as high; while peaty soils rise to 23 per cent. or more.

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[*] Wilda's Centralblatt, 1868, 1, 430.

[†] *Ib.* 1866, 1, 118.

[‡] X Census, 5, 71.

### *Lime Pan.*

One other point of some importance relating to the texture of soils is the tendency noted on stiff soils, the plow depth of which is not varied with some frequency, to form a hard pan or compact layer between the surface and sub-soil. Once formed, it is the tendency of the alkaline silicates, humates and lime carbonate brought to it by the leaching of the surface soil to form a strong layer that prevents the proper upward movement of sub-soil moisture in dry seasons and the free downward movement of the plant roots. Heavy liming, after such a pan is formed, often greatly increases it, forming what is known as lime-pan. This formation is readily prevented, however, by proper liming; but it would be well to be sure that the land is free from hard-pan before heavily liming it.

## THE CHEMICAL EFFECTS OF LIMING.

When the action of lime upon various individual minerals and upon distinct organic materials such as starch, albuminoids, etc., is studied, it is found to be quite variable with the nature of the substance acted upon. That the introduction of so powerful a chemical reagent into those highly differing and always complex mixtures of mineral and vegetable matters that we term "soils," should result in a great variety of effects is not, therefore, surprising. In the discussion following, attention will be chiefly confined to a few of the practically more important points, considering first those relative to the mineral matters and, second, those affecting the organic matter (humus) and nitrogenous substances.

### *Most Soil Constituents Unavailable to Plants.*

Before speaking in detail upon these subjects, it may be remarked that while plants are able to take up directly from freshly pulverized rock materials small quantities of the several plant foods the latter contain, the mineral substances must usually undergo quite radical changes by the action of weather and decaying vegetation before they are really in condition to make a fertile soil. Before they are thus changed, many of them resist the action of quite strong acids; among such minerals are included the widely distributed and important minerals, quartz, feldspar, mica, hornblende, augite, talc, steatite, kaolinite, chrysolite and chlorite.* It is not, therefore, a matter of surprise that in even rich soils, only 50 to 150 parts in 100,000 are capable of being dissolved in water.

It must, of course, be admitted that the plant is not wholly confined in its feeding upon mineral matters to the water-soluble substances; for the acid surfaces of the rootlets and root-hairs are able to take up some mineral matters through their cell walls in much the same manner as the acid strawberry, in the course of preparation for table use, takes up and is sweetened by the coarse, dry, granulated sugar spread upon it.

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*Johnson, How Crops Grow, 329.

We have, however, not discovered a chemical reagent which will closely represent in its action upon the soil, the action of the plant during a single growing season. While it is thought that the mineral matter soluble in hydrochloric acid may fairly represent the ultimate fertility or cropping strength of soils, various organic acids or solutions of their salts have been proposed as reagents to show the more immediately available plant food, such as the plant could probably utilize at once if opportunity occur; these do not all closely correspond in their action with that of various plants, and it is highly improbable that a single solvent could do so for all plants and soils; but they are of considerable value as indicators of the readiness of the various more important soil ingredients for use by the plants, and to afford rough suggestions as to the need for the application of the several manurial constituents.

*Lime Unlocks Plant Food Already in Soil.*

So it has come to be said that only a small proportion of the food substances in most soils are immediately ready for plant use; that the less soluble foods are, as it were, locked up in a safe, and that lime is one of the keys by which the safe may be opened and some of its contents made accessible to the crop. If, however, the soil be devoid of compounds such as lime can convert into available plant food, the addition of lime can cause no increase in the material fertility of the soil except as lime itself may be needed by the plants.

## *Liberation of Potash :*

### Potash in Soil Chiefly Insoluble:

Though the commercial potash compounds are nearly all soluble—with so few exceptions that the chemical methods for the separation of potash from other bases are very limited in number—most of the potash present in the soil exists there in insoluble or difficulty soluble combinations. Drainage waters contain, as a rule, much less of it than of soda, lime or magnesia. Thus Way,* upon examining the drainage waters from seven fertile soils near Surrey, Eng., found in four cases, only traces of potash, and in the others, only 0.03, 0.07 and 0.31 parts in 100,000 parts of the water. Krocker† found, in the summer drainage, from poor soils, only 0.2 to 0.6 parts in 100,000 of the water, but Zöller,‡ in five waters of percolation collected during the summer from a number of soils near Munich, found 0.20 to 0.65

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*Jour. Roy. Ag. Soc., 17, 133.

†Jour. prak. Chem., 60, 466; *Cf.* Johnson, How Crops Feed, 314.

‡Johnson, *Ib.* 315.

parts in 100,000. Dehérain,§ studying the drainage of the experiment farm at Grignon, France, found that on highly manured land the drains in one year removed 0.2 per cent. of the entire acid-soluble potash present, while from unmanured lands, only 0.05 per cent. of the entire amount of potash was removed. Where a proportion of water larger than that found in the soil is used in extraction, or where a soil is exposed to the action of renewed portions of water, larger amounts of potash are found to be dissolved.

### Potash in Fertilizers Fixed by Soils:

Furthermore, if a given amount of some potash salt be added to a sample of soil and, after the mixture has stood for a short time, the earth be washed with water and the washings compared with those obtained by the extraction of an equal quantity of the unmixed earth with an equal quantity of water, it is found that the potash extracted from the former soil is far less than the sum of that in the potash salt and that extracted from the unmixed earth; in other words, it is distinctly evident that much of the potash in soluble fertilizer salts is quite promptly changed in the soil into insoluble or difficultly soluble compounds. The time required for the completion of this fixing action—so far as it goes, for all the fertilizer potash is never fixed,—Peters|| found, in case of one soil, to be forty-eight hours.

### Solvent Action of Lime:

The solvent action of water is, however, very greatly increased when lime, whether as a hydrate, as acid carbonate, or in chlorid, sulfate, nitrate or similar soluble salt, is dissolved in it. The work of Johnson, Way, Liebig, Brustlein, Peters, Knop, Heiden, Armsby and others, has shown most clearly that the lime in such solutions displaces some of the potash of the soil, the displaced alkali being extracted while an equivalent quantity of lime is fixed in the soil. This probably explains the fact noted by Hilgard** that sometimes a soil very rich in lime and phosphoric acid, shows a good productiveness despite a very low potash content; and, conversely, sometimes a high potash content seems capable of offsetting a low lime percentage—it being true that potash salts when added in solution to a soil, liberate some lime with the fixation of an equivalent amount of potash.

### Nature of Compounds Attacked by Lime:

When the nature of the compounds in the soil that are acted upon by the lime with a resulting liberation of potash, is studied, it is found that, for the most part, they belong to two great classes: hydrous

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§Traité de chimie agricole, 426-7.

||Ldw. Vers.-Stat., 2, 140.

**X Census, 5, 78.

soluble silicates, probably belonging to the zeolitic class, and double salts of the acids of humus—humates and ulmates. M. Johnstone,[*] in studying the compounds that result from the weathering of feldspars—anhydrous double silicates of alumina with potash, soda or lime—states that when carbonic acid is present in large quantity, the potash is set free as carbonate; but that when such excess of carbonic acid is lacking, the potash remains in combination with silica; if, then, lime be added, it displaces the potash, forming the lime silicate and setting the potash free, as it has been found to do in acting upon the pure zeolitic minerals.

Mulder[†] has found that humic and ulmic acids form double salts of the alkalies with lime, magnesia, iron, manganese and alumina. It is doubtless due, at least in large measure, to a displacement of potash by lime in a manner analogous to that observed in the case of the double silicates, that liming soils poor in such silicates but containing humus, results in the increase of available potash.

### Solvent Action of Magnesia:

According to Kellner,[‡] magnesia and magnesium salts act in a manner similar to lime. Peters,[§] testing the solvent power of the saline solutions of a number of bases, including lime and magnesia, upon equal portions of a well-washed soil, found that the magnesia solution took out 0.1224 grammes of potash, while lime removed 0.1252 grammes, or with a slight correction for the lack of precise chemical equivalence in the solvent used, the magnesia salts had 90 per cent. of the activity of the corresponding lime salt.

### Amount of Potash in Soils Experimented Upon:

Turning now to the soils subjected to test in our experiments: The proportion of potash in the solutions prepared for the determinations of lime and magnesia, the results of which have been stated in an earlier paragraph, was determined by Mr. C. W. Norris in accordance with the official method. To gain a better notion of the availability of the potash in the several soils, Mr. Norris also determined the proportion of potash extracted by water under the following conditions:

One hundred grammes were soaked with 1,000 c. c. of distilled water at summer temperature (23 degrees C., or 73 degrees Fahr.), for seven days, the flask being thoroughly shaken several times daily. The liquid was then drawn off and the fine silt in suspension allowed to settle. In a given fraction of the clear liquid the potash was determined.

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[*] Naturw. Rundschau, 1891, 323; Exp. Sta. Record, 3, 581.

[†] Chemie der Ackerkrume, quoted by Johnson, How Crops Feed, 230-1.

[‡] American Fertilizer, 6, 245.

[§] Johnson, How Crops Feed, 241.

In a study of soil solvents made, several years since, by Dr. Bernard Dyer, Chemist to the Royal Agricultural Society, England, upon certain soils of the Rothamsted Experiment Station, England, and checked by the analytical crop and fertilizer records, remarkably indicative results were obtained by using a 1 per cent. citric acid solution as the solvent.

The several soils tested were, therefore, examined before treatment with lime, by the use of this solvent. Mr. C. P. Beistle, Assistant Chemist, made these determinations in the following manner: 200 grammes of the air-dried soil was exposed for seven days at summer temperature (73 degrees Fahr.), to the action of two litres of a 1 per cent. solution of citric acid; the mixture was shaken several times daily. At the end of the seven-day period the liquid was decanted off and carefully filtered. In a given fraction of the filtrate, the potash was determined in the manner recommended by Dyer, save that the heavy metals, phosphoric acid, etc., were first precipitated and filtered off.

The results of these three sets of determinations are given in the following table, the figures being the average of two or three closely concordant determinations:

TABLE VIII.—Potash in the Original Soils. (Per Cent.)

| Soil Sample. | Moisture. | In per cent. of the Entire Soil. | | | In per cent. of the Potash Soluble in HCl. | |
|---|---|---|---|---|---|---|
| | | Total. | Citric acid soluble. | Water soluble. | Citric acid soluble. | Water soluble. |
| I. Ironstone, .................. | 2.37 | .326 | .0133 | .0080 | 4.1 | 2.5 |
| II. Black slate, ................ | 2.00 | .885 | .0220 | .0071 | 2.5 | 0.8 |
| III. Red shale clay, ............ | 1.39 | .460 | .0107 | .0060 | 2.3 | 1.1 |
| IV. Limestone clay, ........... | 1.64 | .805 | .0136 | .0068 | 1.7 | 0.8 |
| V. Glacial loam, ............... | 1.96 | .270 | .0117 | .0071 | 4.3 | 2.6 |
| VI. Muck, ...................... | 4.85 | .220 | .0450 | .0290 | 20.5 | 13.2 |
| VII. Limestone clay, ........... | 1.36 | .340 | .0190 | .0120 | 5.6 | 3.5 |
| VIII. Loam, ...................... | 1.49 | .330 | .0150 | .0130 | 4.5 | 3.9 |
| IX. Red shale clay, .......... | 1.73 | .415 | .0150 | .0130 | 3.6 | 3.1 |

The differences in the quantity of water are very small, except in the case of the muck as compared with the other soils; even in the latter case, the correction would be an increase in the percentage of potash in the muck amounting to only one-thirtieth of the portion extracted by the several solvents. Comparisons may, therefore, be made on the basis of the figures as they are stated above. So far as the total amount of potash extracted by strong acid is concerned, No. II, black slate, and No. IV, limestone clay, contain by far the larger quantities, and No. VI, the muck, contains least; while the other soils do not differ very greatly from one another.

The editor of the Handbook of Experiment Station Work (p. 313), notes that this element is capable of great variation without materially affecting the productiveness of the soil. In heavy clay uplands it ranges from 0.8 to 0.5 per cent.; in lighter loams from 0.45 to 0.3; in sandy loams below 0.30., and in sandy loams of great depth may fall below 0.10 with good productiveness and durability.

Hilgard* says "No virgin soil having 0.50 per cent. of potash will wear out first on that side of its store of plant food; and much less will suffice in the presence of much lime and humus."

Water-Soluble Potash:

When we turn to the consideration of the condition in which the potash exists in the soils, several striking facts are apparent. The muck, notwithstanding its low proportion of total potash, contains over twice as much water-soluble potash as an equal weight of any other of the soils, and about six times as much as is present in No. III, red shale clay; looking simply at the percentage of the total potash that is present in water-soluble condition, it is seen to be over sixteen times as great in the muck as in Nos. II and IV. On the contrary, the soils containing the highest percentages of potash soluble in strong acid, Nos. II and IV, are among those containing least of this ingredient in water-soluble condition. The source of the soil, as regards the kind of rock from which it is formed, is not necessarily an indication of its present composition and fertility; thus, compare the limestone clays, IV and VIII, and the red shale clays, III and IX, and quite important differences in the amount and condition of the potash are visible.

Total Available Potash:

Turning to a consideration of the potash dissolved by the citric acid method, none of the soils show less than 0.01 per cent., and so should scarcely be regarded as extremely impoverished. Dyer† suggests that there is no immediate need of potash-manuring, if the citric soluble potash in the soil form 0.005 per cent. of the dry soil. In this case, too, the muck shows both the largest percentage and the largest amount, while Nos. I, III, IV and V contain the least amounts.

Potash in Soils After Treatment:

The treated soils were also examined with reference to the amount and condition of the potash contained. The total potash soluble in strong acid was determined by Mr. C. W. Norris, that soluble in citric acid solution by Mr. C. P. Beistle. In the latter determination a sufficient quantity of citric acid was used, beyond that required to make a 1 per cent. solution, to neutralize the lime and magnesia added in the samples that represented the results of treatments B and C, so that the neutralizing effect of these alkaline earths might not too greatly interfere with the solvent action of the liquid.

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*Rep. Cal. Exp. Station, 1889, 166.

†Jour. Chem. Soc., 1894.

The results are shown in the following table. Owing to the fact that the quantity of the lime and magnesia added in treatments B and C would not, even if fully carbonated by action of the air of the soil, come to equal 1 per cent. of the weight of the entire soil, it has not been deemed needful to correct for the error introduced by this addition, to permit a direct comparison between the results of treatment A and those of B and C. For safety, the moisture of the samples was determined in each case; the differences between the several treated samples and the original soils were, however, so slight that these results may be omitted.

TABLE IX—Potash in the Treated Soils. (Per Cent.)

| Soil. | Treatment A. (Fallow). | | | Treatment B. (Lime.) | | | Treatment C. (Magnesia.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Soluble in strong acid. | Soluble in citric acid. | Proportion of potash soluble in citric acid. | Soluble in strong acid. | Soluble in citric acid. | Proportion of potash soluble in citric acid. | Soluble in strong acid. | Soluble in citric acid. | Proportion of potash soluble in citric acid. |
| I. Ironstone, | .262 | .0133 | 5.1 | .242 | .0155 | 6.4 | .222 | .0176 | 8.0 |
| II. Black slate, | .760 | .0220 | 3.0 | .753 | .0241 | 3.2 | .720 | .0243 | 3.4 |
| III. Red shale clay, | .298 | .0116 | 3.9 | .265 | .0140 | 5.3 | .345 | .0150 | 4.4 |
| IV. Limestone clay, | .543 | .0172 | 3.2 | .572 | .0200 | 3.5 | .557 | .0178 | 3.2 |
| V. Glacial loam, | .195 | .0132 | 6.8 | .185 | .0150 | 8.1 | .225 | .0162 | 7.2 |
| VI. Muck, | .217 | .0320 | 14.7 | .210 | .0340 | 16.2 | .217 | .0334 | 15.4 |
| VII. Limestone clay, | .315 | .0116 | 3.7 | .310 | .0162 | 5.2 | .302 | .0208 | 6.9 |
| VIII. Loam, | .395 | .0128 | 3.2 | .365 | .0144 | 3.9 | .370 | .0168 | 4.5 |
| IX. Red shale clay, | .438 | .0134 | 3.1 | .450 | .0208 | 4.6 | .448 | .0176 | 3.9 |

Examining these figures critically and comparing them with the percentages obtained in the case of the original untreated soils, some very striking discrepancies are seen, especially in the cases of Nos. II, III and IV. Some discrepancy is also apparent in the figures for potash soluble in strong acid obtained from each soil after the different treatments. The latter fact and the further fact that the results are the averages of several separate analyses in each case, lead to the conclusion that the discrepancies are chiefly due to the difficulty in getting perfectly uniform samples of soil, even when great care is exercised.

So far as the potash soluble in strong acids is concerned, there seems to be no evidence in the figures above presented to the effect that the lime or magnesia especially influences the amount of potash that is capable of extraction with such vigorous solvent. There are variations, it is true, in the percentages shown by samples from different treatments of the same soil, but comparing the lime and fallow treatments in their action upon red shale clays, Nos. III and IX, the figures would show exactly opposite effects. It would, however, not be safe on the basis of these analytical results to affirm positively that lime and magnesia have no tendency to attack minerals little soluble in strong acids, and, in greater or less degree, to aid the increase of their availability through the process of weathering.

(a.) Effect of Fallowing:

It may, however, be true that the availability of the potash in the different portions of the same soil is more uniform than is the amount of potash itself. On the basis of this assumption, compare the citric-acid-soluble potash in the original and fallow soils. Despite the opposite tendency of the total potash soluble in strong acid, in soils I, II, III, IV and V, inclusive, after fallow treatment, the proportion of the entire soil present in citric-acid-soluble potash is as great or greater than in the original soils; in the muck soil, the quantity of such potash is materially less after fallowing; in soils VII, VIII and IX it shows a slight decrease; expressed in terms of the entire acid-soluble potash, that soluble in citric acid in the fallow soils is greater in soils I, II, III, IV and V; is somewhat less in soils VII and VIII and markedly less in the muck soil.

(b.) Effect of Liming:

Turning attention now to the effect of lime, recalling that the soils in Treatment A were exposed to precisely the same conditions as those subjected to the other treatments, we may fairly compare the figures from Treatments A and B to ascertain the effect of the liming. Without exception, the "available" potash, or that soluble in citric acid, was increased. If the proportion of the entire soil represented by the "available" potash is considered, it is found that from 16 to 74 pounds, or an average of 30 pounds per million pounds of soil is present in the limed soil. This may appear to be very little, but as little as twenty pounds of nitrate of soda applied to an acre has been found to influence the plant growth and such application is equivalent to no more than 1 pound of nitrogen to 1,000,000 pounds of soil. The larger effects were observed on the limestone clay, No. VII, and on the red shale, No. IX, which, in their original state, contained nearly 0.3 per cent. of lime. Such increase represents, of course, a larger proportion in case of soils poor in potash.

(c.) Effect of Magnesia:

Looking finally to the effect of the magnesia as shown by a similar comparison between the figures from Treatments A and C, the "available" potash is increased from 6 to 92 pounds, or an average of 36 pounds per million of soil. In general, the unlocking or liberating of the potash seems to have been about as well accomplished by the magnesia as by the lime. The ironstone soil, No. I, and limestone clay, No. VII, exhibited the most marked effects from the magnesia treatment. Nothing in the composition of the original soil, as revealed by the analyses made, explains its greater effect upon these soils.

Taking the averages for the nine soils, the proportions of the total potash that was soluble in citric acid were: In the original soils, 5.5 per cent.; in the fallow, 5.2 per cent.; in the limed, 6.3 per cent., and those receiving magnesia, 6.3 per cent.

These results, therefore, agree with those of Kellner, viz: That both lime and magnesia increase the available potash in most soils, and that the magnesia is almost equal to its equivalent proportion of lime in producing this effect. It is further interesting to note that this increased availability resulted from the action of magnesia upon the muck as well as upon the soils less richly supplied with humus.

## *The Effect upon Soil Phosphoric Acid.*

Solubilities of Soil Phosphates:

The phosphoric acid in most rocks is present in the form of tricalcic phosphate, a lime compound that is somewhat soluble in pure water, and much more soluble in water saturated with carbonic acid gas.

Bretschneider[*] found that in twenty-four hours at ordinary temperature one part of finely precipitated tricalcic phosphate required 87,832 parts of water to dissolve it, but only 13,181 parts of carbonic acid water. In the soil, however, a very large proportion of the phosphoric acid is present in the form of phosphate of iron (usually ferric phosphate, for the most part) or alumina. The iron phosphate is much less soluble, the same investigator having found that one part of freshly precipitated ferric phosphate requires for its solution 160,625 parts of water, or 146,570 parts of carbonic acid solution. In the latter case it is seen that the solvent action of the soil water, usually containing considerable carbonic acid, is much less, as compared with pure water, than it is in case of the lime phosphate. Fleischer[†] has found that water dissolves from freshly precipitated phosphate of alumina even less phosphoric acid than it takes up from the corresponding ferric compound.

Johnson[‡] remarks that drainage waters commonly contain phosphoric acid but in quantities too small for accurate estimation.

Availability in Calcareous Soils:

If the soil is rich in lime or magnesia it is thought probable that a fair share of the phosphoric acid will be combined with it and be quite readily dissolved by the plant roots and soil moisture; if, on the contrary, lime and magnesia are deficient, the phosphoric acid is doubtless present in its much less soluble compounds with iron or alumina.

Hilgard,[§] in his study of the cotton soils of the Southern States, dwells upon this point. He notes that less than 0.05 per cent. of phosphoric acid soluble in strong acids is a notable deficiency unless accompanied by much lime; in sandy loams, 0.1 per cent., with a fair supply of lime, secures a fair productiveness for eight to fifteen years, but with a deficiency of lime, 0.2 per cent. of phosphoric acid is required to produce the same result. Three Louisiana soils are cited as illustrative of this fact:

(a) Pine woods sub-soil (Vernon parish) an upland soil producing only 500 lbs. of seed cotton per acre for a few years.

(b) Oak and hickory red sub-soil, upland (Sabine parish), producing 800 to 1,000 lbs. when fresh, then declining.

(c) Anacoco prairie soil (Vernon parish) has yielded 1,200 to 1,500 lbs. for fifteen years and is still doing fairly well.

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[*] Quoted by Storer, *Op. cit.*, (4th ed.), I, 265-6.
[†] *Ib.* 264.
[‡] How Crops Feed, 310-315.
[§] X Census, 5, 78-80.

| | (a.)<br>Per cent. | (b.)<br>Per cent. | (c.)<br>Per cent. |
|---|---|---|---|
| Potash, | 0.247 | 0.202 | 0.332 |
| Lime, | 0.097 | 0.268 | 1.398 |
| Magnesia, | 0.339 | 0.290 | 0.736 |
| Phosphoric acid, | 0.072 | 0.028 | 0.047 |

The observations of Gerlach,* made upon artificially treated soils, show that the phosphates of both lime and magnesia are slowly soluble in water and completely so in carbonated water; but the phosphates of iron and alumina are practically insoluble in these solvents and only incompletely so in dilute organic acids.

Lime Attacks Ferric Phosphates:

There are quite a large number of observations showing that the application of lime to soils deficient in that constituent tends to increase the availability of the phosphoric acid present. Thus, Dehérain,† on mixing calcium carbonate with ferric phosphate and treating the mixture with carbonic acid water, found much tricalcic phosphate in the solution; if, however, lime phosphate was mixed with a large proportion of ferric carbonate, ferric phosphate was formed.

On the basis of this latter observation, this investigator‡ suggests that unless such considerable quantities of lime are used as will predominate over the free sesquioxids of iron and aluminum in the arable layer of the soil, the increased solubility of the soil phosphates will not be accomplished.

Prof. Millot§ observed that the application of soluble phosphates to a soil in the Department of Loire-et-Cher which was rich in iron oxid, gave a benefit, but one very fleeting, no residual effect being observed the second year; the subsequent addition of marl brought an increase in yield such as that land never yields except with a good dressing of phosphate, indicating the restoration of the phosphoric acid to an available condition. This is a fair type of many such observations.

Phosphoric Acid in Soils Experimented Upon:

Turning now to the soils taken for experiment: The amounts of phosphoric acid contained in the several solutions made by extraction of these soils, were determined, in the strong acid and water solutions, by Mr. Norris, and in the citric acid solution by Mr. Beistle. In the latter solution, the results are somewhat unsatisfactory because of the difficulty of prefectly removing the finest particles of soil from the liquid, so that the phosphoric acid obtained represents that in the small particles of soil as well as in the real solution; in determining the potash, the figures for which have already been presented, the chemical methods that were employed threw out the silt, which was not practicable in determining the phosphoric acid:

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*Ldw. Vers. Stat., 46, 201.

†Comptes rendus, 46, 212.

‡Traité de Chimie agricole, 525.

§*Loc. cit.*

TABLE X—Phosphoric Acid in the Original Soils. (Per Cent.)

| Soil Sample. | Percentage in Entire Soil. | | | Proportion in Available Form. | |
|---|---|---|---|---|---|
| | Soluble in strong acid. | Soluble in citric acid. | Soluble in water. | Citric acid soluble. | Water soluble. |
| I. Ironstone, | .060 | .0057 | .0032 | 9.5 | 5.3 |
| II. Black slate, | .204 | .0111 | None. | 5.4 | 0.0 |
| III. Red shale clay, | .080 | .0088 | .0016 | 11.0 | 2.0 |
| IV. Limestone clay, | .140 | .0082 | .0033 | 5.9 | 2.4 |
| V. Glacial loam, | .092 | .0130 | .0040 | 14.1 | 4.3 |
| VI. Muck, | .206 | .0628 | .0015 | 30.5 | 0.7 |
| VII. Limestone clay, | .124 | .0139 | .0027 | 11.2 | 2.2 |
| VIII. Loam, | .127 | .0146 | .0005 | 11.5 | 0.4 |
| IX. Red shale clay, | .151 | .0306 | .0045 | 20.3 | 3.0 |

As for the phosphoric acid soluble in strong acid: Hilgard's average from 466 soils from the humid regions of this country, especially the Southern States, is 0.113 per cent.; from 313 soils from the arid regions, 0.117 per cent.; in general, clay soils were considerably richer than sands. In view of these averages, most of the above soils are fairly well supplied with phosphoric acid, Nos. I, II and V containing least, but even these are not very deficient.

Dehérain* observes that in estimating the sufficiency of the phosphoric acid in a soil, not only its richness as exhibited by analysis, but its depth must be considered in determining the need for phosphatic fertilizers. Thus, he says, M. Nantier, director of the Agricultural Station of Somme, found, near Amiens, a soil containing 0.25 per cent. of phosphoric acid, of which much was available, as shown by the solubility of one-tenth in acetic acid; yet a phosphate dressing increased the yield per acre (French) of beets from 28,500 to 45,000 kilogrammes; for the soil was only from six to eight inches deep, and had scarcely more available phosphoric acid in that depth of soil than one crop would require. He suggests that unless a soil contains more than 0.1 per cent. of phosphoric acid, and more than 0.02 to 0.03

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*Traité de Chim. agricole, 730-1.

per cent. of available phosphoric acid, with such depth of surface soil that the amount of available acid therein shall not be less than about 900 lbs. per acre, phosphate manuring is needed.

Availability of the Phosphoric Acid:

The condition in which the phosphoric acid exists in the several soils is evidently very different; thus, samples II, VI and VIII, despite their comparatively high proportion of phosphoric acid, contain very little that is soluble in water, even less than III, which contains so much less of phosphoric acid as a whole. In No. I, which contains the least of all, there is the largest proportion of the phosphoric acid soluble in water.

Considering the total available phosphoric acid as indicated by the proportion in the entire soil soluble in citric acid, the muck is richest and the red shale clay, IX, next, while the ironstone, I, contains least. Only I, III and IV contain less than 0.01 per cent., the figure fixed by Dyer as indicating need of immediate phosphate application.

Phosphoric Acid in Soils After Treatment:

The effects of liming and application of magnesia upon the availability of the phosphoric acid are shown in the following table:

## TABLE XI—Phosphoric Acid in Treated Soils. (Per Cent.)

| Soil. | Treatment A. (Fallow). | | | Treatment B. (Lime.) | | | Treatment C. (Magnesia.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Soluble in strong acid. | Soluble in citric acid. | Proportion of phosphoric acid available. | Soluble in strong acid. | Soluble in citric acid. | Proportion of phosphoric acid available. | Soluble in strong acid. | Soluble in citric acid. | Proportion of phosphoric acid available. |
| I. Ironstone, | .095 | .0082 | 8.6 | .098 | .0107 | 10.9 | .099 | .0096 | 9.7 |
| II. Black slate, | .227 | .0100 | 4.4 | .233 | .0090 | 3.9 | .206 | .0109 | 5.3 |
| III. Red shale clay, | .089 | .0080 | 9.0 | .084 | .0107 | 12.7 | .080 | .0110 | 13.8 |
| IV. Limestone clay, | .147 | .0064 | 4.4 | .139 | .0152 | 10.9 | .164 | .0126 | 7.7 |
| V. Glacial loam, | .091 | .0100 | 11.0 | .088 | .0132 | 15.0 | .090 | .0164 | 18.2 |
| VI. Muck, | .206 | .0496 | 24.1 | .271 | .0674 | 24.8 | .241 | .0610 | 25.3 |
| VII. Limestone clay, | .124 | .0090 | 7.3 | .142 | .0138 | 9.7 | .163 | .0162 | 9.9 |
| VIII. Loam, | .152 | .0084 | 5.5 | .161 | .0124 | 7.7 | .135 | .0160 | 11.9 |
| IX. Red shale clay, | .135 | .0178 | 13.2 | .153 | .0258 | 16.9 | .145 | .0320 | 22.1 |

While differences in the total phosphoric in the original soil and the corresponding treated soils are observed, just as was the case with potash, the general relations are the same in both the original and treated soils.

(a.) Effect of Fallowing:

Comparing the original and the fallow soils, as regards the proportion of the phosphoric acid in available condition, the latter shows an invariably smaller proportion than the former; this is not always very marked, but in some cases, such as III, V, VI, VII, VIII and IX, for instance, the decrease is considerable.

(b.) Effect of Liming:

Compared with the fallowing, the treatment with lime results in a larger availability of the phosphoric acid than where soil lies fallow, except in the case of II; it is possible that a predominance of iron and alumina in the latter soil may account for this, but as no determinations of iron and alumina were made, it is not certain that this is the correct explanation. On the muck, the liming seemed not to have caused any increase in the availability of the phosphoric acid or to have entirely prevented a decrease; the greatest increases occurred in soils IV, V and IX.

(c.) Effect of Applying Magnesia:

Considering the effect of magnesia, its general tendency was to act as powerfully, at least, as lime. Indeed, if we may form an estimate of the influence of the different treatments upon the availability of phosphoric acid, the following averages will be suggested: Of the total phosphoric acid, the citric acid took from the nine soils by Treatment A, 9.7 per cent.; by Treatment B, 12.5 per cent.; by Treatment C, 14.0 per cent. While inference from averages is not always safe, it does not seem that lime acted in these cases more effectively than magnesia; in soils V, VIII and IX the increase with magnesia was much the greater, while IV showed a considerably less effect than with lime. As in the case of lime, soils II and VI alone failed to show a marked increase in the availability of the phosphoric acid.

Influence upon Subsequent Application of Phosphates:

There is another important consideration in the use of lime, viz: Its influence upon the immediate availability and upon the duration of effect of phosphatic fertilizers applied to a limed soil.

Reversion of Phosphoric Acid in Fertliizer:

It is a well-known fact that in the manufacture of superphosphates, if the soluble phosphoric acid, or rather water-soluble phosphates formed by the action of sulfuric acid upon tricalcic phosphate, the so-called "bone phosphate of lime," be brought into contact with wood ashes, lime or even fresh portions of raw phosphates, the soluble compounds will be wholly or in part reverted or reconverted into tricalcic phosphate, differing from the original only in being more finely sub-divided than is possible by a purely mechanical process. The chemically precipitated phosphate is much more soluble than that occurring in nature; thus, Warington[*] found that, at ordinary temperatures, there were required of water saturated with carbonic acid gas, to dissolve one part of pure precipitated tricalcic phosphate, 1,789 parts; to dissolve one part of the phosphate of lime in bone ash, 6,788 parts. Voelcker[†] found that 4,900 parts of water dissolve one part of pure precipitated tri-magnesia phosphate, while 12,610 parts were required for similarly prepared tricalcic phosphate.

### Reversion in Soil:

Now, it is clear that very shortly after their introduction into the soil, soluble phosphates must be converted into less soluble compounds, whether of lime, magnesia, iron or alumina, unless the soil be one containing neither the earthy carbonates nor the oxids of iron and aluminum. Such soils are very rare. Farsky[‡] found that in twenty-four hours, over 60 per cent. of the water-soluble phosphoric acid of acid phosphate applied to a certain soil had lost its capacity of solution in water. In such cases the principal advantage of acidulation of the phosphate must be found in its more thorough dissemination in the soil and in the finer state of subdivision obtained than can be secured by the mechanical pulverization and stirring in of raw phosphates.

### In Non-Ferruginous Sandy Soils and Peats:

In non-ferruginous sands and peaty soils, the addition of lime would result in a quicker conversion to less soluble form, of any acidulated phosphate later applied. In the absence of lime, this "fixation" would not occur and while the soluble phosphate could be somewhat more promptly taken up by the plant, it is far more likely to lose by leaching and to cause injury to the crop by over-concentration. Soils that are artificially deprived of basic material by action of strong acids, exhibit a similar inability to "fix" phosphoric acid.

### In Ferruginous Soils:

In the absence of lime or magnesia, there is a tendency to immediate union with iron oxid or alumina, with the result of an almost immediate loss of availability. It is, therefore, urged in behalf of lime and magnesia that their presence results in a far greater duration of effect from superphosphates than could otherwise be secured; and their application to a non-calcareous soil must greatly increase the value of later applications of soluble phosphates as well as increase the availability of the phosphatic compounds already present in the soil.

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[*] *Cf* Storer, I, 262.

[†] *Loc. cit.*

[‡] Rep. Pa. Agr. Exp. Station, 1887.

Kellner, Sakano, Sato and Shinjo[*] found that lime added to a deep, yellow sub-soil of an irrigated field did not prevent the quick conversion of a subsequently applied dressing of water-soluble phosphate into a form not capable of solution in neutral ammonium citrate. This may have been because the quantities of lime applied (equivalent to from 0.25 to 5.0 per cent. of the soil) may not have equalled the oxids of iron and alumina present. On a "paddy" soil of the same geological origin, but rich in organic matter, the lime retarded the formation of the insoluble phosphates, especially where the proportion of lime was over 1 per cent. of the air-dry soil. Kellner believes, however, that the humus of the paddy soil is useful in accomplishing part of this retardation.

### In Calcareous Soils:

Voelcker[†] notes that heavy dressings of rich superphosphates are not nearly so valuable on the sandy soils of England as on calcareous soils.

### Choice of Phosphates for Different Soils:

Dehérain[‡] urges that long cultivated soils are those for which soluble phosphates are best adapted. On old, non-calcareous soils he regards the basic slag phosphates, which themselves contain lime in caustic or carbonate form, as preferable; and only on old grass lands newly cultivated or on virgin soils rich in organic matter does he recommend the *trial* of non-acidulated phosphates. Bernard,[§] upon the basis of numerous observations as well as upon theoretical considerations, strongly advocates the same selection.

### Liming Incompatible with Use of Non-Acidulated Phosphates:

Speaking of the use of lime with raw phosphates, Dehérain[**] observes that the latter should never be used simultaneously with lime, since the latter will prevent the solvent action of organic acids upon the phosphates. In France, where non-acidulated bone-black used to be employed as a fertilizer, it was found to yield no benefit either with or after a liming; if, however, the liming follows a year later, an increase in the efficiency of the phosphoric acid, by that time partially changed to the iron and aluminum compounds, was exhibited, from causes already explained. These remarks apply better to raw lime phosphates than to those of iron or alumina.

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[*] Bulletin No. 9, College of Agriculture, Tokio, Japan; Exp. Sta. Record, **2**, 764-5.

[†] Quoted by Storer, II, 286.

[‡] Traité de Chim. agricole, 769-770.

[§] Le Calcaire, 91-120.

[**] *Op. cit.*, 760-761.

### Fixation by Magnesia:

Kellner* claims for magnesia also a strong influence in retarding the reversion of phosphates in the soil.

## *Influence of Lime upon the Weathering of Rocks.*

### Double Silicates Influence Soil Retentiveness:

In discussing the effect of lime as a liberator of potash in the soils, it was noted that among the minerals most largely attacked were the hydrous double silicates of potash and alumina. The investigators mentioned in that connection have found that, commonly, an excess of a potash salt or ammonium salt is capable, when introduced into a soil containing a hydrous double silicate of lime and alumina of displacing the lime and leaving the potash or ammonia fixed in the silicate. It is obvious that the presence of a goodly proportion of such double silicates must contribute very largely to that store of fertility which, if not at once fully available, comes into activity in response to good tillage and enables the soil to withstand the drain of heavy, continuous cropping; and, also, to the ability of the soil to take up and retain in fairly available form, without undue waste by leaching, such heavy dressings of potash and ammonium compounds as it may receive—a property often lacking in lighter soils.

### Lime Promotes Weathering and Formation of Double Silicates:

Numerous investigations show both directly and indirectly that lime greatly promotes the weathering of minerals; thus, making their constituents available to the plant, and especially contributes to the formation of this valuable class of soil components, the double silicates. A little of the evidence bearing particularly upon this latter point may be of interest.

Hydraulic cements are found to contain large quantities of hydrous double silicates of lime and alumina; the setting under water is attributed to the formation of crystals of these compounds as they complete their hydration. These cements can be artificially made by mixing certain clays of volcanic origin, or burned clays with moist lime. Many clays which themselves show little tendency to be acted upon by hydrochloric acid, as the hydrous double silicates readily are, are largely decomposed by it after having been exposed for a week or two to the action of milk of lime.

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*American Fertilizer, 6, 245.

Storer* notes the fact that old mortars are often found to contain notable quantities of hydrous silicates, so that caustic lime must be able to attack even the strongly resistant grains of sand. In the same connection, he presents the results of experiments by Stöckhardt proving that lime attacks powdered quartz as well as gelatinous silica, forming a hydrous lime silicate, and that it also decomposes powdered feldspar—a mineral which resists the action of strong acids. Liming is said to be especially efficacious upon such clays as contain broken but undecomposed fragments of feldspar.

By this increase of weathering, therefore, not only is the amount of free potash made more abundant, but the retentiveness of the soil and its durability are at the same time enlarged.

Indeed, numerous laboratory experiments show that many soils gain greatly, by admixture of lime or lime carbonates or other of its salts, in their power to fix potash, soda, ammonia, etc.

It is, furthermore, evident that the liming of sandy soils, especially of those largely made up from minerals other than quartz, in addition to any value it gives in a direct contribution to the food supply in the soil, must also tend to secure a most important benefit in increased retentiveness for added fertility, a property in which such soils are very deficient.

## Importance of Lime in Clay-Burning:

The expensive process of clay-burning so much used upon certain soils of England and Germany, a few decades since, was unproductive of any beneficial results, Lloyd states, unless lime was present in the clay. Storer† asserts, however, that all plastic clays are benefitted in texture if properly burned, but that those containing lime are most benefitted. Voelcker‡ found that a clay containing 31.38 per cent. of calcium carbonate and 58.62 per cent. of real clay gave the following results, in terms of the entire soil:

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**Op. cit.* II. 150.

†*Op. cit.*. II, 280-1.

‡ Quoted by Storer, I, 283.

| | Total acid soluble. | Potash soluble in acid. |
|---|---|---|
| | Per cent. | Per cent. |
| Before burning, | 44 | 0.35 |
| Moderately roasted, | 49 | 0.77 |
| Properly roasted, | 54 | ........... |

Similar results were obtained on other soils by other investigators. Undoubtedly, therefore, one of the most important beneficial results from this treatment is found in the increased proportion of alkaline silicates and more highly available potash in the soil.

### *Reactions upon the Soluble Salts of Potash and Soda.*

Potash and soda are contained in soils not alone in the form of anhydrous and hydrous silicates, but also to a greater or less extent in the form of soluble salts. Upon this class of compounds, as well as the former, lime reacts with important results.

Lime and Salt Composts:

The use of salt with lime in composting peat and other vegetable matters has been largely practiced. The lime decomposes the salt, forming calcium chlorid and caustic soda; the latter of the two resulting compounds being the more readily diffusible, separates in a porous compost from the chlorid and reacts more powerfully than caustic lime in decomposing the vegetable matter. Prof. S. W. Johnson* found a compost of peat and ashes, with lime in one case, and lime and salt in another, gave crops of pop-corn of 43.22 and 46.42 grammes weight respectively, showing the superior activity of the latter agency for decomposition.

Storer† suggests that this may afford a possible explanation for certain exceptionally good results obtained from dressings of salt applied to limestone soil, the soda compound formed in this case being

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*Cited by Storer, *Op. cit.*, II, 19.

†*Op. cit.*, II, 168-9.

the carbonate, however, rather than the hydrate, or caustic soda. A similar reaction would take place with potash salts.

### Lime as a Preventive Against Incrustation:

Heinrich[*] notes than a frequent consequence of heavy applications of soluble fertilizers (kainit, nitrate of soda, etc.) to the soil is the formation of troublesome crusts upon the surface that are only temporarily remedied by cultivation, the next rain being followed by a reappearance of the crust. The simultaneous use of lime, preferably in the form of carbonate, with such fertilizers, is recommended by him as a very excellent preventive against the incrustation.

Lime and calcareous marls have also been found valuable as corrections for the white alkali soils of the arid regions of the west, when these soils contain much of the sulfate or chlorid of magnesium and similar salts.

### Excess of Alkaline Hydrates and Carbonates May Work Injury:

It may easily happen, however, that the alkaline hydrates or carbonates that prove such valuable aids in decomposing humus, may occur in such excess as to cause decided injury. It is a well established fact that these materials have an influence upon the texture of clay soils opposite to that of lime, causing such a soil to puddle, become plastic and remain moist. Even on light, sandy soils, heavy dressings of wood ashes have produced such a degree of coherence between the particles as to make plowing a difficult matter. In the "black alkali" soils of California, Hilgard[†] has found large quantities of sodium carbonate and, in consequence of its influence, these soils are most refractory; furthermore, in the great excess in which the salt is present, it seems to work corrosively upon the vegetation that starts growth upon these soils.

It is entirely possible, therefore, that the reactions between the alkaline salts and lime, either the hydrate or carbonate, that occur when large dressings of lime are applied to lands heavily impregnated with these salts, or when the latter are applied in large quantities to clay lands rich in calcium carbonate, may produce so large quantities of the sodium or potassium hydrates or carbonates as to work injury. Indeed, Heinrich[‡] states that he has, in two instances, observed injurious results from the application of marl (used because of the calcium carbonate it contains), once upon land in whose neighborhood a deposit of salt was later discovered, and once upon soil that had received heavy applications of sewage, which is always rich in common salt.

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[*] Mergel u. Mergeln, 18.

[†] Bulletin 3, U. S. Weather Bureau.

[‡] *Op. cit.*, 16.

### *Lime Corrects Harmful Influence of Ferrous Salts:*

There are often found in such soils as are shut off from free access of air, such as stiff sub-soils and undrained swamps and moors, ferrous compounds produced probably by the reduction of ferric salts or ferric oxids and hydrates. Even after swamps and marshes have been reclaimed, it is probable that in the presence of the large amounts of organic matter such lands contain, there can not be an immediate, complete oxidation of such compounds to ferric forms. Maercker* asserts that the presence even of considerable quantities of ferrous oxid does not necessarily render moor earth uncultivable, so long as the iron remains in insoluble combinations, such as a double ferrous and calcic humate, for example.

While it is true that the humates and ulmates of iron are nearly insoluble in water, Mulder† found the ferrous compounds of apocrenic and crenic acids to be soluble. Since, therefore, the latter compounds are likely to occur in sub-soils and marshy lands, it is not improbable that a part of the marked infertility of fresh turned, yellow clay sub-soils and of recently drained marsh lands is due to these compounds as well as to the sulfates, whose action will be discussed later.

The cause of their injurious effect is not fully understood. The more commonly accepted theory attributes the ill effect to the avidity with which they take up oxygen, robbing the plant roots of their requisite supply.

If such soils be limed, the iron is thrown down in an insoluble form and may then be slowly oxidized without working so great injury to vegetation.

## *Lime Corrects Soil Acidity:*

### Formation of Sulfids in Soils:

In discussing the sources of the lime present in our limestone formations, mention was made of the fact that in the waters of certain springs and in the mud of the sea bottoms, calcium sulfate is being constantly reduced to the form of sulfid, largely through the agency of living organisms. A similar reduction of the sulfate of lime and ferrous sulfate occurs when they are in contact with large proportions of decomposing organic matter. Dehérain,* applying gypsum (sulfate of lime) to soils of varying richness, found after a month that from a soil moderately rich in organic matter, 0.55 gr. of sulfuric acid had disappeared, from a soil containing more humus, 0.100 gr., and from a marsh soil, 0.347 gr.

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*Quoted by Storer, I, 480.

†Quoted by Johnson, How Crops Feed, 221.

### Sulfids Often Oxidize to Injurious Sulfates:

These sulfids sometimes decompose, under the influence of carbonic acid, with the formation of the corresponding carbonates, the sulfur going off in the form of sulfuretted hydrogen.. But in many marshes, bogs and moors they accumulate, the iron sulfid in particular.

These sulfids appear to be directly injurious to plants, but it is probable that a large part of the damage they work is due to the sulfuric acid and ferrous sulfates they form when oxidized. For Farsky† has shown that the direct addition to free sulfuric acid to soils is injurious to vegetation, and Mulder‡ found that humic acid liberates sulfuric acid from ferrous sulfate.

### Occurrence in Marsh Lands:

In the reclamation of the sea bottoms practiced in Holland, the injurious action of sulfids and sulfates has been experienced and it doubtless occurs to some degree in all cases of reclamation of tidewater marshes, and of the bottoms of quiet pools and dams. It is noted, in the management of the old Acadian dyke-lands of Nova Scotia, which are flooded every few years and then again drained, that after such renovation the lands remain almost entirely unproductive for a year or two. It is possible that this is due in part to the sulfids, as well as to the sea salts taken up by the earth.

### Occurrence Below Coal Strata:

There are many limited areas in Pennsylvania lying just below and receiving the leachings from the coal outcrops and the contiguous slate strata, that are almost wholly unproductive because of the ferrous sulfate and sulfuric acid formed by the oxidation of the iron pyrites in the coal and slate and seeping into these lower soils.

### Injuries by Mine Water:

There are also in our State hundreds of acres of once fertile river and creek bottom lands, through which pass streams receiving mine

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*Traité de Chim. agricole, 546-7.
†Bied. Centralbl., 1886, 453.
‡Chemie der Ackerkrume, II, 87.

waters charged with free acid, ferrous sulfate and pyrites-containing culm, that have become sterile because of deposits of the culm upon their surface and the percolation of the acid waters into their pores Even where the layer of culm is not heavy, the sulfates and acids formed from the pyrites often prove wholly destructive to all valuable vegetation, wild blackberries, dewberries and certain weeds taking the place. Coming upon light, sandy alluvium not very rich in lime or magnesia at the outset, such deposits work an injury that is permanent through many years, and sometimes utterly destructive if the land be left to the corrective action of natural agencies.

Lime as a Corrective:*

If, however, lime, either in the caustic condition or as carbonate, be applied to such lands, the free acid is at once neutralized and the ferrous salt soon decomposed into harmless compounds, and even the pyrites more rapidly converted into non-injurious ferric oxid and calcium sulfate. Magnesium hydrate or carbonate would also promptly neutralize the free acid and decompose the ferrous salts.

Such dressings of lime might not be very effective, however, in case of lands injured by mine-water, if the acid water were constantly rising by percolation from the sub-soil, or if the surface soil were so situated as to receive frequent and large deposits of culm.

Litmus Test for Soil Acidity:

If the "burning" and partial or entire failure of good grasses, clover, and cereals upon the soil and the substitution of the characteristic vegetation above mentioned, is not an entirely conclusive proof of the nature of the injury, a direct chemical test may be made to determine whether or not the soil is acid. It must be frankly admitted that the existing tests used for this purpose are not as delicate and conclusive as is desired, owing, in large measure, to the action of the carbonic acid which is to some degree present in the air and moisture of most soils; consequently, the detection of slight acidity is a matter of uncertainty even when the test is applied by an experienced chemist.

The litmus test is one applicable to soils devoid of humus as well as to those rich in that constituent. Litmus is a vegetable dye which turns to a very pronounced blue tint in alkaline solution, and to a bright to pinkish red in acid solution. It is most conveniently applied by means of strips of paper dyed with the coloring matter. A few cents' worth of the blue litmus paper should be purchased from the druggist, and with as little handling as possible, placed in a stoppered or corked bottle and kept in the dark, because sunlight causes the tints to fade. The most satisfactory method proposed for applying this test is that of Dr. H. J. Wheeler:* "A tablespoonful or more of soil is placed in a tumbler or cup and moistened with sufficient water to make the mass of about the consistency of thick paste; allow it to stand for fifteen to twenty minutes before making the test. With a knife-blade part the soil and insert one end of a strip of the paper, press the soil about the paper and after two to five minutes remove the paper without tearing it; rinse off the adhering soil with water and note whether it still retains a blue tint or has become positively red. If the soil has a reddish tint, it may be better to bring but one side of the paper into contact with it, and if a red color comes through to the other side it may be concluded that the soil is acid. Care must be taken not to handle the end of the paper used in making the test, since the touch of the fingers may redden it." Fresh-boiled and cooled rain water is best employed for moistening the soil. If there be much carbonic acid in the soil moisture, a permanent wine-red color may be obtained; but this is not indicative of injurious acidity. If a drop of very dilute vinegar be brought upon the paper, it will give the kind of tint that an acid soil imparts, though the latter is often fainter. Any soil giving this tint needs an alkaline treatment; if the acidity is very slight, it may be temporarily corrected by use of well-rotted stable manure, but if considerable, requires the more powerful and permanent action of lime, caustic or carbonate.

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*Bulletin 46, R. I. Exp. Sta., pp. 100-101.

### Acidity from Fertilizers:

It sometimes happens that an acid phosphate applied to a non-calcareous soil, or in large quantities, to one moderately rich in lime or magnesia, or upon very dry soil, or with very imperfect admixture with the soil owing to the manner of application, produces a temporary acidity in the neighborhood of the germinating seed or young cuttings, with the result that they are "burned" and often killed. On highly calcareous soils or on such as have recently received a moderate dressing of lime, such injury is far less frequent. Also, there was placed upon the market, about twenty years ago, an imperfectly prepared sulfate of potash, which was really an acid sulfate of potash; it wrought injury in the same way. There is little, if any, of this preparation now on sale, as a very simple method of preparing a safe product from the imperfect material has been discovered.

### Acidity Caused by Selective Absorption of Bases by Plants:

A third cause affecting the soil reaction is found in the power which plants possess of selective absorption of the base or acid of a salt, leaving in the soil the unabsorbed residue. There are several views as to the point at which the decomposition of the salt actually occurs, but the fact of such selective absorption is thoroughly established. This was first noted by Stohmann and, later, Kühn* found that upon growing maize in solutions containing ammonium chlorid, the ammonia was absorbed, leaving a residue of hydrochloric acid in the liquid that accumulated to such strength as to kill the plants. In other cases, such as those of tri-calcium phosphate or sodium nitrate, the plant tends to use more of the acid than of the base, leaving the latter in the soil. Adolph Mayer[*] groups the more important fertilizer compounds according to their result upon soil reaction as follows:

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*Henneberg's Journal, 1864, pp. 116 and 125.

*Neutral:* Calcium sulfate (gypsum), magnesium sulfate, sodium chlorid (common salt), superphosphate and potassium nitrate.

*Acid:* Potassium chlorid (muriate of potash), ammonium sulfate, potassium sulfate and German potash salts in general.

*Basic or alkaline:* Calcium carbonate, wood ashes, caustic lime, potassium carbonate, undissolved calcium phosphate, sodium nitrate (nitrate of soda) and bone meal.

The kind of selection made varies also with the plant; thus, wheat and clover grow with roots intermixed, yet the former takes up more of silica than any other ash constituent, while clover retains little of this acid compound but accumulates the bases, lime being the most characteristic.

It must not be inferred from the foregoing statements that, given a sufficiency of food supply, the plant is wholly uninfluenced in its ash composition by the nature of the soluble materials in the soil, for all plants seem to take up, under such circumstances, an excess of the soluble salt without making any use of it in tissue formation.

### Acidity from Humus:

A fourth and the most general cause of soil acidity is the acid humus resulting from the decay and slow oxidation of the vegetable matter, leaves, stubble, roots, inverted sod or green manures in the soil. The formation of the common plant acids, oxalic, tartaric, citric, etc., is the result of oxidations within the plant. Sugar, starch, gums and woody matters form, under the action of oxidizing chemicals or ferments, acetic, lactic, saccharic, mucic and oxalic acids; and when the same substances are acted upon by boiling hydrochloric acid or strong potash lye, brown or black substances are formed closely resembling those that are extractable by the aid of alkalies, caustic or carbonated, from most soils, and separable from these extracts when the latter are made slightly acid. When thoroughly washed, these precipitates are found to be distinctly acid and capable of decomposing some mineral salts. The acid from dark peat is almost black in color and is called *humic acid;* that from brown peats and ordinary soils is commonly brown and is termed

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[*] Ldw. Vers. Stat., 23, 94-5.

*ulmic acid;* there are other more highly oxidized acids present, but more difficultly separable, known as apocrenic and crenic acids, and many others are present in minute quantities. It is very doubtful whether the true nature of these acids of the humus has yet been ascertained, since their separation in a pure state is very difficult. Fremy,* on the basis of its composition and solubility in alkaline carbonate solutions, believes humus to be derived from the ligneous matter or *vasculose*, as he terms it, of the woody tissues that have suffered incomplete oxidation in the soil. Whatever may be the true solution of its origin and constitution, these facts are clear: That the organic matters of the soil undergo a gradual oxidation whereby vegetable tissues lose all appearance of structure, acids are formed and, if conditions favor, are finally completely oxidized to form water, carbonic acid gas and certain nitrogenous compounds. If the access of air be imperfect, as when the soil is low and filled with standing water, the humus may accumulate; in cold climates this is especially the tendency, as the mossy tundras of Britsh North America, the heaths of Scotland, the moors of North Germany and the bogs of Ireland witness; but in warmer latitudes, as along the Amazon, the decay is so rapid that a few years suffice to remove all traces even of a giant tree trunk felled to earth.

In low, wet swamps and marshes where the alkaline and calcareous matters are deficient, the result is, of course, that acids form far in excess of the neutralizing power of the bases present. A similar result may occur temporarily where a heavy green-manuring crop is turned under by the plow in a non-calcareous soil or in a calcareous soil with which it is incompletely mixed from lack of proper tillage.

The free acid in such cases is not wholly composed of these humus compounds, for both humic and ulmic acid have been found by Eichhorn† to possess the power of uniting with the bases of the common neutral salts of the alkalies and alkaline earths, liberating their mineral acids; this reaction is rarely complete, however, a portion of the free acidity being directly due to humus acids.

The free acid is injurious to valuable grasses and most cultivated crops, both directly and indirectly, by affecting the bacterial life in the soil, upon which many of its desirable changes depend, and by bringing into solution poisonous ferrous compounds.

Most cultivable soils are faintly acid, owing to the presence of carbonic acid in the soil moisture, but any excess of acidity due to the four causes just considered is highly prejudicial.

Lowland Acid Soils:

Owing to the fact that marshes and swamps naturally occupy low positions and that, owing to the tendency of lime to pass by leaching from the table lands and slopes to the valleys, the occurrence of decidedly acid lowland soils, even among woodlands, as Tacke[*] has shown, is quite rare, it has come to be generally thought among agricultural writers that soil acidity is a subject requiring little consideration.

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*Cf. Dehérain, Traité de Chimie agricole, 241 seq.; 293.

†Cf. Storer, I, 432.

Upland Acid Soils:

When it is recalled, however, that many soils are derived from rocks poor in lime, such, for example, as certain granites, and that the lime, even of a soil originally rich in that constituent, is sometimes almost wholly removed by leaching from an upland, it is not surprising that a careful examination of soils so situated reveals many instances of markedly injurious acidity. Thus, Muntz and Girard[†] mention large areas of sandy soils in Brittany, Limousin and other sections of France as distinctly acid; Schultz-Lupitz[‡] states that the sandy soil in his section of Germany is deficient in lime and sour, and Ditmar[§] and Hübner[||] mention the frequent acidity of sandy soils; Hilgard[**] has noted such acidity in the sandy uplands of the Southern States and Ruffin[††] long since noted the occurrence of extensive tracts of that character in Virginia, while Wheeler and his associates have made certain the acid character of large areas of Rhode Island and Southern Massachusetts, whose soil is of granite origin.

Upon considering that the major portion of the uplands in Pennsylvania are composed of soils derived from geological formations that are not conspicuously calcareous, and also that the vegetation characteristic of many of these upland soils is made up of distinctly calcifuge plants, such as the chestnut, hemlock, etc., it may be confidently anticipated that a careful examination of these soils would reveal the existence of many tracts rendered infertile by reason of acidity.

Ammonia Water Test:

Wheeler[‡‡] gives another useful test based upon the fact that ammonia water remains nearly colorless in contact with the humates or ulmates of lime and magnesia, but forms a dark colored solution, usually brown or black, when these alkaline earths are not present in sufficient quantity to neutralize the humus acids.

The test is made by introducing some of the soil to be tested into a small bottle, partially filling the latter with rain water, adding a few drops of strong ammonia water, corking the bottle, shaking and allowing the soil to settle. The reaction is not always immediate, sometimes requiring several hours for its completion. The presence of a faint yellow color is not to be regarded; but if the tint be dark yellow, brown or black, the presence of acid humus is indicated.

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[*] See p. 64. [†] Les Engrais, III, 190-191. [‡] Die Kalidüngung auf leichten Boden, 25. [§] Ldw. Vers. Stat., 14, 277. [||] Schulze's Lehrb. Chem. Landw. (4th ed.), 588. [**] X Census, 5, etc.: All quoted by Wheeler. [††] Rep. R. I. Agr. Exp. Sta., 1895, 232 *seq.*

[‡‡] R. I. Ag. Exp. Station, Bull. 46.

## Action of Lime on Muck Soils:

The application of lime very quickly corrects the acidity of drained swamps and marshes, and large applications are sometimes made upon new soils of this character in fitting them for the growing of vegetables, such as onions, celery, etc. The heavy yields resulting from the action of wood ashes, derived from burning brush-heaps, upon newly cleared timber lands are, often, in part attributable to such destruction of a mild acidity. Where the practice of applying peat for fertilizing land is practised, it has long been noted that the raw or crude peat frequently works injury instead of benefit; if, however, the peat be allowed to drain and season for some months, the injurious effect is decreased. The mere weathering of the peat may result in oxidizing any sulfids and ferrous salts contained and improve its texture, but could scarcely correct its acidity; if, however, the peat be composted with lime, the acidity is promptly corrected and the compost is very soon in readiness for use.

The following pot experiment made by Johnson* shows the effect of such treatment upon the crop obtained:

| Soil. | Comparative weight of crop. |
|---|---|
| 1. Peat alone, | 1 |
| 3. Peat and ashes, | 8 |
| 4. Peat, ashes and slaked lime, | 10 |

## Action of Lime on Light Acid Soils:

Some pot experiments by Wheeler† show the relative effect of air-slaked lime, which neutralizes humus, and calcium sulfate, which has no such power. Upon light, acid soils dressed, in addition, with (a) nitrate of soda and muriate of potash and with (b) nitrate of potash respectively, the percentage of gain from the use of lime over that of the land plaster or calcium sulfate was as follows:

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*Peat and Its Uses; quoted by Storer, II, 19.

†Rep. R. I. Agr. Exp. Sta., 1895, 269.

| | (a) | (b) |
|---|---|---|
| Sugar Beets: | | |
| Roots, | 207.52 | 83.15 |
| Tops, | 124.66 | 46.19 |
| Table Beets: | | |
| Roots, | 96.05 | 56.96 |
| Tops, | 30.47 | 30.36 |

Clearly, the lime had a most important effect in neutralizing the acidity, and the selective absorption exercised by the sugar beet left a considerable residue of mineral acid in the soil.

### Magnesia as a Neutralizing Agent:

As for the effect of magnesia in correcting acidity, the remark of Low[*] that magnesian lime is especially efficient upon peaty soils may be recalled; this efficiency may arise from the fact that under favorable conditions for chemical combination, 71 pounds of magnesia can unite with as much acid as would require 100 pounds of pure lime. Kellner[†] commends its efficiency as a neutralizing agent for acid soils. Dehérain[‡] refers to the magnesian marls of England as reputed to possess a very special action, which is far from being explained.

Wheeler,[§] in two successive years, grew mangels upon the light, acid soil of Rhode Island, to which, in addition to equal annual dressings with relatively abundant quantities of nitrate of soda and dissolved bone-black, several neutralizing agents were added together with potash salts. The pots 1 and 2 received carbonate of potash only —in 1894, 5.84 grms.; in 1895, 7.7 grms. Pots 3 to 10 received muriate of potash—in 1894, 7.36 grms. each; in 1895, 10 grms. The other distinctive characters of treatment, together with the weights of air-dried roots harvested, are shown below:

| Number. | Pots. | Alkali added. | | Yield. | |
|---|---|---|---|---|---|
| | | 1894. | 1895. | 1894. | 1895. |
| | | Grammes. | Grammes. | Grammes. | Grammes. |
| 1. | Carbonate of potash only, | ............ | ............ | 53.6 | 44.0 |
| 2. | Carbonate of potash only, | ............ | ............ | 67.1 | 58.0 |
| | Muriate of Potash Pots. | | | | |
| 3. | Caustic magnesia, | 3.81 | 3.81 | 89.9 | 100.1 |
| 4. | Caustic magnesia, | 7.62 | 7.62 | 130.0 | 126.3 |
| 5. | Carbonate of soda, | 8.3 | 8.3 | 123.4 | 131.5 |
| 6. | Carbonate of soda, | 16.6 | 16.6 | 133.5 | 131.3 |
| 7. | No alkali, | ............ | ............ | 91.7 | 51.2 |
| 8. | No alkali, | ............ | ............ | 89.7 | 91.3 |
| 9. | Air-slaked lime, | 91.98 | 18.4 | 144.2 | 148.2 |
| 10. | Air-slaked lime, | 91.98 | 18.4 | 125.8 | 132.0 |

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[*] *Cf.* p. 69.

[†] American Fertilizer, 6, 245.

[‡] *Op. cit.*, 518.

[§] *Op. cit.*, 265.

The conditions of moisture and food supply were such as to make the chief variable almost certainly the different neutralizing power of the several alkaline substances. The caustic magnesia is seen to have been almost as efficient as its chemical equivalent of carbonate of soda, and to fall not far below a very much larger quantity of air-slaked lime.

Upon acid soils, therefore, dressings of magnesian lime, if not made excessive in quantity, will be as effectual, if not more effectual than those of equal weights of purer limes.

### Reaction of Soils Experimented Upon:

In discussing the state of combination of the lime and magnesia contained in the soils experimented upon, it was assumed* that all the carbonic acid removed from the original soils by the action of a current of carbonic-acid-free air and of warm hydrochloric acid, had been present in the soil in the form of calcium carbonate. It might be inferred that since each soil yielded some carbonic acid under this treatment, all must contain calcium carbonate and, hence, none could be acid in reaction. The inference is not strictly warranted because some of the carbonic acid may have formed in the air of the soil from the oxidation of organic matter, though the conditions were not favorable to any active oxidation; it is notable that while the combined percentages of lime and magnesia varied from 0.21 to 1.58 per cent., those of carbonic acid only ranged from 0.025 to 0.048 per cent. Another ground upon which the inference may be questioned is the authority of Stöckhardt† and of Mondesir‡ for the belief that small quantities of calcium carbonate may remain undecomposed in a distinctly acid soil, possibly because of the large grain of its particles or because it is not uniformly distributed.

The water-soluble acidity was determined by Mr. Beistle in the aqueous extract made by washing 20 grammes of each soil, upon a funnel, with about 100 c. c. of distilled water and titrating with very weak (deci-normal) soda solution, using phenol-phthalein as an indicator. In all but four cases, only one drop of the alkali was sufficient to neutralize the acidity, but in these cases the quantities requisite were:

| No. | Volume of alkali required. |
|---|---|
| 5, | 0.05 c. c. |
| 6, | 0.90 c. c. |
| 8, | 0.10 c. c. |
| 9, | 0.05 c. c. |

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*Cf. Table VI. p. 75.

†Jb. Ag. Chem., 1866, 10.

‡Ann. sci. agron., 1887, 2, 273-4.

Such a test, however perfectly it might be performed, would not suffice to show any acid constituents that are insoluble in water.

Mr. C. W. Norris applied the litmus test, using a very sensitive paper; all the soils showed some acidity, but it was decided only in cases of Nos. 5, 6, 8 and 9. A repetition some days later gave the same results. The very faint acidity is, of course, not indicative of a condition prejudicial to plant life, as has already been remarked.

The ammonia test was also applied by Mr. Norris by shaking 150 grammes (over four ounces) of the dry soil with distilled water to which a few drops of strong ammonia had been added, and noting any coloration evident a short time after the deposition of the sediment. The results were:

I. No coloration.
II. Light brown color.
III. No coloration.
IV. No coloration.
V. Decided brown color.
VI. Very deep brown color.
VII. Light brown color.
VIII. Light brown color.
IX. Light brown color.

Judging from the three tests, No. VI was strongly acid, No. V distinctly so, and Nos. VIII and IX slightly. A portion of the good results observed to follow liming on these soils must be attributed to their neutralization.

## *Influence of Lime upon the Organic Matter of Soils.*

The organic matter of the soil is for the most part the partially oxidized residue from pre-existing vegetation; the composition must be, in a measure, dependent upon the kind and proportion of the ash constituents, nitrogenous bodies and woody and other carbohydrate matters of which the plants were composed, as well as upon the conditions of their decay.

### Ultimate Composition of Humus:

This decay is accompanied by a liberation of carbonic acid, but if we may judge from the composition of the ulmic and humic acids formed artificially from sugar, the loss of carbon is less than of the other elements, for of dextrose it constitutes 40 per cent.; of humic acid, 64 per cent., and of ulmic acid, 67.1 per cent., according to Mulder.[*] It may be that the large proportion of carbon found in humus is in part due to the more complete destruction of the readily fermentable substances, such as sugar, starch, etc., leaving in the residue a larger proportion of those modified celluloses—lignin bodies, hemi-celluloses, cutose, etc.—which are richer in carbon than the more common and more fermentable carbohydrates. Thus, Fremy, treating wood with alkaline carbonates, extracted a group of substances separable from the extract by its acidulation. This precipitate he supposed to be one substance, with a content of 59.3 per cent. of carbon, which he termed *vasculose.* It is more readily obtained from straw than from wood.

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[*] *Cf.* Johnson, How Crops Feed, 226-7.

### Selective Fermentations Due to Living Organisms:

Such a selective destruction occurs in the plant itself, when deprived of its leaf food and has been observed in the curing tobacco leaf[*] and in the decay of sweet fruits. In all these cases, either the living plant itself or a lower organism is the effective agent in producing the bio-chemical changes observed.

The presence in the soil of numerous lower organisms, moulds or bacteria, is so thoroughly established in numerous investigations that it is sufficient here to simply affirm the fact.

### Fermentation of Stable Manure:

The studies of Reiset,[†] Hebert,[‡] Guyon,[§] Schloesing fils[||] and Dehérain[**] upon the changes which the straw forming the litter of stable manure undergoes during the fermentation of the manure, are highly suggestive in this connection. In brief, they found that the sugar and closely related substances of the straw are destroyed by a ferment acting in the presence of air to form carbonic acid and liberate free nitrogen, while the cellulose is destroyed by another ferment, stirred to activity whenever air is admitted, but continuing to act in its absence, which liberates some carbonic acid and more marsh gas. There is left the "vasculose" in a modified condition, partially dissolved in the alkaline liquids of the fermented manure. Upon the evaporation of this solution, a shining black substance is left containing about 40 per cent. of ash, 36 per cent. of vasculose and 24 per cent. of nitrogenous substances. The ash contains, strange to consider, phosphoric acid, lime and ferric oxid; in the absence of the organic materials these phosphates could not exist together in a neutral or alkaline liquid. The nitrogenous material too, while its proportion can be diminished by repeated resolution and reprecipitation,* can never be wholly dissociated.

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[*] *Cf.* Rep. Penna. State College, 1894, p. 190. *seq.*

[†] *Cf.* Dehérain, Traité, 683.

[‡] Ann. agron., 16, 358.

[§] Comptes rendus, 98, 528.

[||] Comptes rendus, 108, 529; 109. 886; Ann. Agron. 18, 5.

[**] *Op. cit.*, 678 *seq.*

### Fermentations of Various Soils Differ:

The nature of the changes which vegetable matters undergo by the activity of the various soil ferments has not, at least so far as the non-nitrogenous constituents are concerned, been so closely worked out as have those to which the litter of stable manure is subject. There is much reason to believe that the reaction of the soil, and possibly other conditions, exercises a very decisive influence over the kind and rate of the changes occurring within its pores. It may be true of the soil humus, as Schloesing fils found it to be of stable manure—which differed from clean litter in this respect—that change is not wholly prevented when the activity of the ferment organisms is precluded, so that it may be regarded as due in part to direct chemical action; but it is more probable that the principal agents by which fresh vegetable matter is converted into humus are fermentative or biological. The latter view leads to the expectation of dissimilarities in decomposition governed not only by climatic conditions and soil composition, but possibly also, by differences in the nature of the ferments present in different soils.

With this view of the agencies by which humus is formed, it is interesting to observe that the humus of different soils shows great variation in its solubilities, its power to support certain types of vegetation, the bacterial life present in it and the proportions of nitrogen and mineral matters closely associated with it.

### Grandeau's Matiere Noire:

Upon treating soils with an alkaline liquid, after a previous treatment with an acid for the removal of readily soluble basic materials, Grandeau was able to extract a portion of the humus which, upon evaporation of the solution, shows an appearance similar to the black matter extracted from stable manure by alkaline solutions; and, like the latter, this black matter of the soil—*matiere noire*, as chemists continue to call it—contains ash ingredients that do not show their presence under ordinary tests until the organic substance is destroyed by ignition, or until subjected to dialysis, which enables them to pass through a membrane that holds back the organic substance. As in the case of the stable manure, not only silica and potash, but the ordinarily incompatible substances, phosphoric acid, lime and ferric oxid are found in the associated mineral matter; while nitrogen, too, is as closely associated as in the similar manure extract.

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*Cf. Ann. agron., **14**, 116.

### Its Relations to Fertility:

Grandeau contends that the *matiere noire*, which is particularly abundant in *mild humus*, such as that of old garden soils, is an important solvent of the mineral matters useful as plant foods, and that the immediate fertility of a soil is in large measure determined by the amount of the mineral foods that are present in chemical combination with the *matiere noire*. This is still a debatable point, but there are many interesting facts affording some foundation for Grandeau's theory. He himself observed that the associated mineral substances in the *matiere noire* are more abundant in fertile than in sterile soil, and found them to vary from 2 to 60 per cent. of the entire extract.[*] Hilgard[†] found that in the extremely fertile "sugar-bowl delta" lands of the Brazos River, Texas, and in the bottom lands of the Colorado River of the West, in California, the entire amount of phosphoric acid is present in the *matiere noire*, while in poor lands a much smaller fraction of the entire phosphoric acid contained was present in such combination. Snyder,[‡] in analysis of certain soils from the famous wheat lands of the Red River Valley, found that the wheat yield upon those soils seems to bear a closer relation to the amount of phosphoric acid contained in the *matiere noire* than to that of any other constituent, this element of fertility showing a rapid decrease under the exhaustive system of continuous wheat culture still largely practiced in that locality.

Dehérain[§] goes further, and asserts that while wheat may do without it, a certain portion of the *matiere noire* is indispensable to the best growth of clover and other legumes.

### Popular Views as to the Influence of Lime Upon Humus:

With this view of the nature of humus we may turn to the influence of lime upon its amount and condition. It is generally admitted from practical experience that liming often promotes the rapid decomposition of green manures, sod and peat, with the formation of a very desirable humus, but that oft-repeated, heavy liming tends, on many soils, to a final depletion of the humus supply to such a point as to seriously affect their mechanical condition and general fertility. Thus, even the surface soil of moor lands[||] is brought to such a low humus content that it is needful to turn up the humus-rich subsoil in order to continue the cropping of the land.

### Exact Investigations Upon Loss of Carbon:

The exact investigations made upon loss of carbonaceous matter from humus soils show quite wide variations. The subject has recently been quite elaborately discussed by E. Wollny;[*] after noting that dilute acids retard or prevent the decay of humus, that very dilute caustic alkali favors it, but strong solutions retard it, and that weak solutions of alkaline carbonates promote it especially, if the decay has already begun, he calls attention to the following results of investigation: E. Wolff[†] found that caustic lime added to fresh manure, which was then kept under cover, greatly diminished the loss, by decay, of both total organic matter and nitrogen. J. Nessler,[‡] applying lime to turf and variously prepared bone-meals, found decay at first retarded, then increased, but with a total decrease from liming in the loss observed for a twelve-months' period. P. Petersen[§] found the amount of carbonic acid given off from acid leaf mould greatly increased upon addition of calcium carbonate, the increase being far too great to be explained by any decomposition of the added carbonate. Wollny,[||] himself, has made extensive investigations upon this subject. Addition of lime to artificial soils, the one containing as its humus material, rye straw, the other turf, found the evolution of carbonic acid diminished as the lime increased in the case of the rye straw, but increased in case of the turf. Other investigations in which turf, horse dung and humus from a sandy soil were used with different soil combinations, agreed in showing at first a decrease after liming (which is possibly due to absorption of the carbonic acid by the lime) followed by an increase, and later by a decrease; that is, while lime favors a rapid progress in the early stages of the fermentation, it has a later conservative influence.

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[*] *Cf.* Storer, I, 487.

[†] X Census, 5, 81.

[‡] Bulletin 53, Minn. Exp. Station.

[§] Ann. agron. 9, 68; Traité, 523-4, 547.

[||] *Cf.* Heinrich, Mergel u. Mergeln, 30-31.

Relations of Lime to Matiere Noire:

A number of investigators are of the opinion that lime is a conservator of the *matiere noire*. Dehérain[**] notes that lime salts precipitate most, but not all, of the *matiere noire* of stable manure from solution and holds that this explains the observation of P. Thenard that while the drainage waters of recently manured sandy soils are sometimes discolored, those from calcareous soils are not. Mulder[††] had earlier observed a similar precipitation of humate of ammonia (equivalent in part to Grandeau's *matiere noire*) by caustic lime and magnesia, calcium and magnesium chlorids and by ferric, ferrous and manganic sulfates. Kostycheff,[‡‡] studying the causes that have led to the production of the wonderfully fertile black soil of Russia, commonly termed *tschernosem*, believes that the coloration is due to changes, in the presence of lime compounds, resulting in the formation of substances which, like the group of substances related to tannin, blacken by oxidation on exposure to the air. Hilgard[*] notes that lime brings about a more rapid transformation of vegetable matter into *active humus* (*matiero noire*), manifest in the deep black tint of the soil—a tint which is not present except when there is abundance of alkaline or alkaline earthy carbonate also present. He further affirms that lime protects the *matiere noire* from the oxidizing influences of a hot climate. On ordinary uplands, tending to a lime deficiency, he finds only 0.4 to 0.7 per cent. of *matiere noire;* in the more prominently calcareous soils, 1 to 1.5 per cent. or even more. He also considers that the lime materially influences the proportion of the phosphoric acid that is present in the *matiere noire;* while there are exceptions noted, as a general rule soils rich in lime contain most, and occasionally all, of their phosphoric acid in this combination, while soils poor in lime contain only one-fourth to one-tenth of their phosphoric acid in similar condition.

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[*] Die Zersetzung d. organischen Stoffe, 128-134.
[†] Ldw. Vers Stat., 1859, 141.
[‡] Ber. Arb. Grossh. Vers. St. Karlsruhe, 1870, 93-103.
[§] Ldw. Vers. St., **13**, 155-175.
[||] *Op cit.* and J. f. Ldw., 1886, 261.
[**] Traité, 523.
[††] Chem. d. Ackerkrume, quoted by Johnson, How Crops Feed, 231.
[††] Ann. agron. **17**, 17.

A. Bernard[†] observes that calcium carbonate unites with *matiere noire* to form a compound not soluble in ammonia until the lime be first removed by acid treatment.

On the other hand, Wollny[‡] found a greater evolution of carbonic acid from a pure calcium humate than from acid humus, indicating that some, at least, of the materials present in the later stages of decomposition are not preserved from further decay by liming, but rather hastened therein. Kellner[§] found an increased loss after liming both upland and paddy soil (the latter formed under conditions of submergence for part of the year), but much greater in the latter soil.

### Liming Increases Retentiveness of Humus:

It is quite generally agreed that the liming of humus tends to increase its power to fix potash and ammonia in soils where lime has previously been deficient.[||]

### Changes in the Organic Matter of the Soils Under Experiment:

In our experiments a careful study was made of the amount of total organic matter and of active humus (*matiere noire*) in soils VI (muck) and VII (limestone clay) after treatment by fallowing, and by applications of lime and magnesia respectively. The work upon these points was performed, upon portions of the treated soils used for the analyses previously reported, by Mr. M. S. McDowell, Assistant Chemist of the Experiment Station.

Van Bemmelen[**] having called attention to the fact that in the ordinary method of determining moisture by drying the soil at the temperature of boiling water, other volatile matters and water of crystallization and of combination in both mineral and organic matters might be driven off, an additional determination was made of the loss of water by the soil upon suspension in a cooled bottle (temperature 3 degrees to 15 degrees C.), over sulfuric acid until the weight of the sample no longer decreased.

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[*] X Census, 5, 77, 81; Bull. 3, U. S. Weather Bureau.

[†] Le Calcaire, 150.

[‡] *Loc. cit.*

[§] Bull. 9, College of Agriculture, Tokio, Japan; Exp. Sta. Record, 2, 762.

[||] *Cf.* Storer, I, 496.

[**] Ldw. Vers. Stat.

In addition, determinations of the total loss upon ignition and of the *matiere noire* extractable by the Huston-Grandeau* method were made. All determinations are based upon duplicate tests.

The results were as follows:

TABLE XII—Organic Matter in Air Dry Soils. (Per Cent.)

| Determinations. | Muck. VI. | | | Limestone Clay. VII. | | |
|---|---|---|---|---|---|---|
| | Fallow. | Lime. | Magnesia. | Fallow. | Lime. | Magnesia. |
| 1. Moisture lost at 3°-15°C, ..... | 2.13 | 1.75 | 2.06 | .36 | .29 | .27 |
| 2. Additional loss at 100°C,...... | 3.94 | 3.35 | 3.68 | .92 | .97 | .96 |
| Total moisture (1+2), ...... | (6.07) | (5.10) | (5.76) | (1.28) | (1.26) | (1.23) |
| 3. Total loss by ignition, ........ | 21.83 | 21.75 | 22.22 | 5.36 | 5.38 | 5.49 |
| Organic Matter. (3—Total moisture), ...... | (15.76) | (16.65) | (16.46) | (4.08) | (†4.12) | (4.26) |
| 4. *Matiere noire*, ................. | 8.17 | 7.46 | 7.60 | 2.20 | 1.44 | 1.63 |
| Per cent. of organic matter present as "matiere noire," | (51.84) | (44.80) | (46.17) | (50.39) | (*34.95) | (38.26) |

*Corrected for carbonic acid lost by ignition, 36.68. †Similarly corrected, 3.92.

As to the moisture, these results seem to indicate that only a small part of the loss of weight from the air-dry soil when it is heated at the boiling point of water, is removable at the ordinary temperature in the manner previously described—the losses over sulfuric acid being, from the muck, one-third, and from the limestone clay only one-fourth of the entire loss. If it be true that the excess of loss at 100 degrees C. over that at ordinary temperature under these conditions, is due to loss of water of combination, these soils seem to have undergone a great deal of dehydration in the drying process. The subject merits an investigation with more complete checks.

It is not surprising to find the air-dry muck holding so much more water than No. VII, as that is the tendency of soils highly charged with organic materials.

The *total organic matter* has been estimated by subtracting from the percentage of loss occurring upon careful ignition, the *total moisture* lost at 100 degrees C. Admittedly this tends to give a figure too high. Not all the water of crystallization of minerals is given off at the temperature of boiling water, but the residue is expelled upon ignition; again, complete ignition tends to dissociate any carbonates present in the soil, liberating the carbonic acid. But the amount of carbonic acid in the original material of these soils amounted to only 0.04 per cent. (*circa*), while that in the treated soils was as follows:

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*Proc. Assoc. Official Agr. Chem., 1896, 42.

| | No. VI. | No. VII. |
|---|---|---|
| Lime treatment, | 0.069 | 0.202 |
| Magnesia treatment, | 0.090 | 0.068 |

So that, except in the case of the limed soil, VII, the correction for this loss would not be appreciable; but if it be assumed that all the carbonic acid was expelled in the ignition of the limed soil, No. VII, then the total organic matter will be more nearly 3.92 per cent., and the proportion of it present as *matiere noire* would be 36.68 per cent. There are no data by which a correction for the former of the two sources of error can be made.

The active humus in the original soils was earlier determined by Mr. W. S. Sweetser, then Assistant Chemist of the Experiment Station; calculated to their proportions in the water-free soil, the percentages of humus in the original and the fallow soils are:

| | VI. | VII. |
|---|---|---|
| Original, | 3.23 | 2.18 |
| Fallow, | 3.59 | 2.23 |

So that little change in this constituent appears to have resulted from the fallowing.

As for the preserving action of the two applications, it appears that in the muck soil there was less loss of total humus in the soils treated with lime and magnesia, but that there was a distinctly greater diminution of the *matiere noire.*

In the limestone clay soils, the figures for total organic matter agree too closely to warrant any distinction, but here, too, the amount of *matiere noire* was found considerably less in the soils receiving lime and magnesia. In both soils, the decrease of *matiere noire* was less with magnesia than with lime.

Under the conditions of our experiments, therefore, liming, or the application of magnesia in liberal dressings is found not to preserve but to destroy the active humus more rapidly than that which is less soluble.

## *Effect of Lime upon the Nitrogenous Substances of the Soil:*

### Relative Gain of Nitrogen in Formation of Humus:

Kostytscheff,* in his studies of the formation of the black soils of Russia, to which reference has already been made, observed that nitrogen was lost during the decay of the plants from which the humus is, in this case, derived, much less rapidly than carbon, so that, while it amounted to only 1 to 2 per cent. of the plants, the humus contained 4 to 6 per cent.

Hilgard and Jaffa† found that this divergent tendency is magnified in arid regions as shown by the following figures:

| | Number of samples. | Humus in soil. | Nitrogen in humus. | Humic nitrogen in entire soil. |
|---|---|---|---|---|
| | | Per cent. | Per cent. | Per cent. |
| Arid soils, | 18 | .75 | 15.87 | .101 |
| Semi-arid soils, | 8 | .99 | 10.66 | .102 |
| Humid soils, | 8 | 3.04 | 5.24 | .123 |

In extreme cases they found more than 6 per cent. of nitrogen, the average in pure albuminoids, in the humus of arid soils.

Dehérain‡ states, on the basis of analyses by Boussingault, Truchot and himself, that the ratio of nitrogen to carbon in various soils ranges, in arable lands (nitrogen being taken as the unit of comparison) from 4.8 to 45.0, and in prairie or grass lands from 6.8 to 20.0, the percentage of nitrogen in the soil varying in the arable lands from 0.046 to 1.05, and in the grass lands from 0.180 to 0.940.

### Condition of Nitrogen in Soils:

Way,§ in examining certain drainage waters, found from 2.78 to 21.05 parts of nitric acid in 100,000 parts of the water, and only from

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*Ann. agron., 17, 17.

†Agricultural Science (1894).

‡Traité, 392.

§Jour. Roy. Soc., 17, 123.

0.009 to 0.025 parts of ammonia. The nitric acid was more abundant than any single base.

It must not, however, be inferred from this that the soil ordinarily contains large quantities of soluble nitrogen compounds. On the contrary, the major portion is present in difficultly soluble form, despite the fact that in the leaves and stalks from which the humus is formed, much of it is present in soluble amid compounds, such as asparagin. Furthermore, the nitrogenous matter is not nearly as liable to putrefactive fermentation as are the albuminoids of plant and animal tissues.

The nitrogen of the soil has been found chiefly in three classes of compounds: in ammonium salts, in nitrates and in organic matter. But very little of it is commonly present in the first two classes of compounds. Boussingault,[*] for example, found in the garden soil of Liebfrauenberg, the following proportions of nitrogen in the various states of combination:

| | | |
|---|---|---|
| Total nitrogen, ................. | 0.261 | per cent. |
| Ammonia, ....................... | 0.0022 | per cent. |
| Nitric acid, ..................... | 0.00034 | per cent. |

That is, only 4 per cent. of the total nitrogen was present in the more soluble combinations. This soil, the investigator found, despite its richness in nitrogen, would not, when prevented from receiving the nitrogen compounds, that come in the rain, yield much more material to growing crops than the latter were able to obtain from barren soils.[†]

It appears then that plants must, for the most part, take their nitrogen from the soil, either in the form of ammonia or of nitric acid.

The beautiful research of Muntz[‡] has shown that, in the entire absence of nitrates and of the conditions to which their formation is due, plants can take up the nitrogen they need directly from ammonium compounds.

But the great fertilizer value of the nitrates has been known since the sixteenth century, and they have been shown by the interesting researches of Berthelot and André[§] to be present in all plants at some stage in their lives.

## Causes of Formation of Ammonia and Nitric Acid in Soils:

There was formerly much difficulty in accounting satisfactorily by rational chemical theories for the varying transformations of the inert nitrogenous substances into the ammonium compounds and nitrates. It is now known that the formation of both classes of compounds is chiefly due to the action of living organisms (bacteria) upon the inert nitrogenous substance of the soil.

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[*] Agronomie, I.

[†] *Cf.* Johnson, How Crops Feed, 280-281.

[‡] Dehérain, Traité, 109-110.

[§] Ann. chem. phys. [6] 8, 75-128.

Our present knowledge upon these changes is due chiefly to the investigations of Berthelot and André,[*] Schloesing and Muntz,[†] Winogradsky[‡] and Warington.[§] There seem to be three classes of organisms concerned in the transformations:

1. An ammonical ferment changing organic nitrogen to ammonia.
2. A nitrous ferment, converting the ammonia to nitrites.
3. And possibly a nitric ferment accomplishing the oxidation of nitrites to nitrates.

Under proper conditions for nitrification, as the conversion to nitrates is termed, the ammonia is oxidized even more rapidly than it is formed from organic matter. The conditions for favorable action are: 1. Free circulation of air in the soil. Illustrative of this condition is the recent observation of Kellner and others[||] that the liming of a dry soil to which ground fish had been added induced a rapid nitrification, while in the submerged soil of the "paddy" field, the fermentation stopped with the formation of ammonia. 2. A suitable degree of moisture. 3. The presence of the active ferment. 4. The presence of a base with which nitric acid may combine as it forms, since the fermentation ceases with the appearance of acidity. 5. A temperature ranging between 40 degrees and 113 degrees Fahr.

It has been observed that in undrained marsh lands and especially in forest soils that nitrates do not form. Frank notes the great development of moulds in the forest soil and that the trees are devoid of fine absorbent root-hairs, but have the growing portions of their root systems throughly penetrated by the thin hair-like hyphae of these moulds; he suggests, therefore, the probability that the moulds attack the inert organic matter and act as purveyors thereof to the trees.[**]

Nature of Inert Nitrogenous Compounds:

There is much uncertainty as to the real state of combination of the inert nitrogen in the humus. Johnson,[††] on the basis of the behavior of this nitrogen with alkaline earths, such as lime; of the fact that albuminoids, such as are present in the plant, commonly yield amids upon decomposition, and that the reversion of ammonia to inert forms, which sometimes takes place in the soil, is most readily explained by this hypothesis, suggests the probability that the combination is of an amid nature.

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[*] Ann. chim. phys. [6], 11, 375.

[†] *Cf.* Dehérain, Traité, 403.

[‡] Ann. de l'Institut Pasteur, 4, 213.

[§] *Cf.*. Dehérain, *Op. cit.*, 108.

[||] Bull. 9, College of Agr., Tokio, Japan; Exp. Sta. Rec., 2, 764.

[**] *Cf.* Also Storer, I, 417-419.

[††] How Crops Feed, 276-280.

Influence of Lime on Soil Ammonia:

Concerning the effect of lime upon the nitrogenous constituents of the soil: It is common laboratory experience that on the addition of caustic lime or carbonate of lime to solutions of ammonium salts, at ordinary temperatures, ammonia is liberated.

A. Bernard[*] finds, that upon application of ammonium sulfate to soils containing no more than 1 per cent. of lime, a liberation of ammonia occurs in from five to ten minutes.

It is probable that ammoniacal fermentation of the soil is promoted by the presence of calcium carbonate; but an excess of the caustic lime would tend to be injurious to the ferments. Ladureau[†] observed that the addition of lime to a 2 per cent. solution of urea retarded the action of the ammonicial ferment in proportion to the amount of lime introduced.

Lime Affects Nitrification:

As to the influence of lime compounds on nitrification: Touvenal[‡] long since observed that the formation of nitre in nitre-beds is most favorably affected by the use of chalk and pure carbonate of lime. But quick-lime he found to be much less useful. Boussingault[§] found that caustic lime caused a loss of ammonia from garden soil and a hindrance of nitrification. Indeed, an excess of it in the presence of moist earth may induce putrefaction and a consequent destruction of nitrates. Warington[||] found that lime water was twice as strongly alkaline as is desirable for the best development of the nitric ferment. Very heavy limings have been observed to materially reduce the richness of vegetation of a soil for the first year, but to conduce to a rankness of growth thereafter, indicating that the lime had meanwhile been converted from the caustic into the carbonated form. Bernard, therefore, suggests that it is dangerous to apply caustic lime to an already calcareous soil, and Wollny[**] cites experiences of Pichard,[††] Warington[‡‡] and Dumont and Crochetelle[§§] to the effect that where there is already a tendency to alkalinity, applications of sulfate of lime or of potash would be more helpful than even the corresponding carbonates.

On the other hand, Bernard[|| ||] notes that on non-calcereous soils, organic materials, even those so readily nitrifiable as dried blood, often fail to show markedly beneficial results and require, in the absence of liming, direct applications of nitrates or ammonium salts to supply the requisite nitrogen. Muntz and Girard* observe that the distinctly acid soils of Brittany and also the non-calcareous soils of Limousin set up little nitrification in added fertilizers unless the latter can supply the requisite alkali.

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[*] Le Calcaire, 68-75.

[†] C. R. 90, 887.

[‡] *Cf.* Storer, I, 301.

[§] Storer, *Loc. Cit*

[||] Ann. agron., 14, 49.

[**] *Op cit.*, 186.

[††] C. R. 89, 1289 114, 490.

[‡‡] Ann. agron., 14, 557.

[§§] C. R., 117, 670.

[|| ||] *Op. cit.* 76-87.

Kellner has observed that magnesia affects nitrification favorably, but Winogradsky was led to prefer lime compounds instead of the magnesium salts he earlier used in his culture fluids for the nitrifying bacteria.

Nitrogen in Soils Under Experiment:

The observations upon the changes which the nitrogen in the several soils experimented upon, underwent as the result of the several treatments, were confined to Nos. VI and VII.

In addition to the determinations of moisture, organic matter and active humus already discussed, there were determined:

1. Total nitrogen by the official Scovell-Kjeldahl method, working upon 2 g. of No. VI and 20 g. of No. VII.

2. Nitric and ammoniacal nitrogen combined, using the official Ulsch-Street method, working upon 20 g. of the soil.

3. Ammoniacal nitrogen: 20 grammes of the soil were distilled under reduced pressure with caustic magnesia; enough of the reagent was used to make the liquid distinctly alkaline, 5 g. being the usual amount. It is well known that the accuracy of the method is impaired by the tendency of amids, if present to liberate their nitrogen in the form of ammonia, when brought into contact with alkaline earths, lime being more powerful than magnesia. It has been suggested that under reduced pressure, the latter reagent will not effect so extensive decomposition.

Under my direction, Mr. W. S. Sweetser distilled various amid substances at ordinary pressures and at a pressure so reduced that the boiling point of the liquid ranged from only 32 degrees to 38 degrees C. The amounts of ammonia found in the distillate are expressed in terms of their equivalent of decinormal ammonia solution (3.5 g. ammonium hydrate to the litre). O. P.=Ordinary pressure; V.=In vacuo:

TABLE XIII—Liberation of Ammonia from Organic Substances upon Distillation.

| | Cubic centimeters of N-10 ammonia equivalent. |
|---|---|
| 250 distilled water with 5 g. caustic magnesia, ............ | 0.1 |
| .10 g. urea, in distilled water (O. P.), ...................... | 1.8 |
| .10 g. urea, in distilled water (V.), ......................... | 1.7 |
| .10 g. urea, in distilled water with 5 g. caustic magnesia (O. P.), ............................................ | 2.0 |

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*Ann. agron., 17. 297.

| | Cubic centimeters of N-10 ammonia equivalent. |
|---|---|
| .10 g. urea, in distilled water with 5 g. caustic magnesia (V.), | 0.4 |
| .10 g. uric acid, in distilled water with caustic magnesia (V.), | 0.6 |
| .20 g. asparagin, in distilled water (V.), .................... | 0.5 |

Some loss occurs even on boiling in pure water at reduced pressures; caustic magnesia did not appreciably increase this loss.

4. Humus nitrogen was separately determined in an aliquot portion of an extract prepared by the Huston-Grandeau method, except that 3 per cent. caustic soda instead of 4 per cent. ammonia water was used as the solvent; the Kjeldahl method of nitrogen determination was used.

5. There are present in the soil several types of amid bodies. Some of these, being acid amids, give up their ammonia when heated with a strong acid. To estimate the nitrogen in this state of combination, 100 g. of the soil was suspended in 500 c. c. of water, containing 15 g. of strong hydrochloric acid, and kept upon a water-bath for forty-eight hours. The total nitrogen in an aliquot of the carefully filtered liquid was determined and the amid nitrogen estimated by subtracting from the amount of nitrogen thus found, the sum of the nitric and ammoniacal nitrogen. It is not sure that all the acid-amid nitrogen it recoverable under these conditions, but is believed that most of it should be.

Attempts were also made to separate the nitrogen present in form of amido acids, if any, by treatment with nitrous acid; but thus far we have not succeeded in preparing a satisfactory working method for such materials. The determinations in the original soil were made by Mr. W. S. Sweetser; in the treated soils by Mr. M. S. McDowell. The results obtained are given in terms of the water-free soil.

TABLE XIV—Nitrogen in Original and Treated Soils. (Per Cent. of Water-Free Soil.)

| Determination. | Muck. (No. VI.) | | | | Limestone Clay. (No. VII.) | | | |
|---|---|---|---|---|---|---|---|---|
| | Original. | Fallow. | Lime. | Magnesia. | Original. | Fallow. | Lime. | Magnesia. |
| Loss by ignition (total organic matter), | ............ | 23.24 | 22.92 | 23.58 | ............ | 5.44 | 5.46 | 5.56 |
| Humus (matiere noire), | 8.33 | 8.59 | 7.86 | 8.15 | 2.18 | 2.23 | 1.46 | 1.65 |
| Total nitrogen, | .578 | .618 | .595 | .597 | .116 | .130 | .125 | .119 |
| Ammoniacal nitrogen, | .0134 | .0053 | .0003 | .0042 | .0027 | .0024 | .0013 | .0010 |
| Nitric nitrogen, | .0310 | .0341 | .0474 | .0419 | .0125 | .0134 | .0167 | .0201 |
| Amid nitrogen, | .2657 | .2938 | .2537 | .2467 | .0379 | .0467 | .0458 | .0347 |
| Other organic nitrogen, | .2679 | .2848 | .2936 | .3042 | .0629 | .0675 | .0612 | .0632 |
| Nitrogen in Humus. | | | | | | | | |
| a. Per cent. of entire soil, | .4012 | .3706 | .2929 | .2950 | .0824 | .0558 | .0486 | .0456 |
| b. Per cent. of humus, | 4.82 | 4.36 | 3.73 | 3.62 | 3.78 | 2.50 | 3.29 | 2.76 |
| Proportion of Total Nitrogen in the Several Nitrogenous Compounds. | | | | | | | | |
| Ammoniacal, | 2.32 | .86 | .05 | .71 | 2.29 | 1.80 | 1.06 | .85 |
| Nitric, | 5.37 | 5.52 | 7.96 | 7.02 | 10.83 | 10.39 | 13.41 | 17.35 |
| Amid, | 46.00 | 47.59 | 42.62 | 41.30 | 32.75 | 35.94 | 36.79 | 29.23 |
| Other organic compounds, | 46.31 | 46.08 | 49.37 | 50.97 | 54.13 | 51.87 | 48.74 | 52.57 |
| (Humus), | (69.47) | (60.00) | (49.20) | (49.38) | (71.10) | (42.97) | (39.02) | (38.46) |

It is to be remembered that here, as in preceding cases, the results reported are averages of several closely agreeing determinations, and that the sub-sample representing the "original" soil probably differs more from those representing the results of the several treatments than do the latter from each other.

A direct comparison of the *original* and *fallow* soils is not possible, but some conclusions of value may be had from a comparison of the proportions in which the nitrogen is represented in the several classes of compounds in the two sets of samples.

In both the muck and limestone clay there is a smaller proportion to the total nitrogen present in ammoniacal combination. In the muck, there is a little more present in nitric compounds, but in the clay considerably less.

There is more nitrogen present in amid combination, whether by reason of a primary formation of ammonia and its subsequent fixation in that form, or by direct transformation of other nitrogenous organic compounds, it is, of course, not possible to judge.

More of the nitrogen than is represented in the amid compounds is found in the active humus. The proportion of the total nitrogen present in the active humus is less in the fallow soil than in the original untreated sample. Evidently the fermentative changes occurring during the fallowing have resulted in making the nitrogenous substances of the organic matter relatively less soluble in alkaline liquids. This retrogression is particularly observed in the cultivated limestone-clay soil.

Comparing more closely the figures for the fallow soil and those receiving lime and magnesia respectively, these facts appear:

The total nitrogen in the soil is slightly diminished in the limed soils and those receiving magnesia; this may possibly be due to a loss from the ammoniacal compounds, which are less in their residual amount in both lots of soil representing the effects of these treatments than they are in the fallow samples.

The nitrates are more abundant, very considerably so, where the alkaline earths were applied. In the muck, the magnesian treatment showed less nitrates; in the limestone-clay, more nitrates than the lime treatment.

In both cases there was also a marked decrease in the nitrogen present in amid condition, far greater than the increase of nitrates can counter-balance; in other words, whether by reason of appropriation in the organism of the ferment present or by simple chemical change, the nitrogen appears to have reverted in part to an even less readily decomposable form than the amid compounds. This was particularly true of the muck soil.

In both cases, also, the "matiere noire" contains more nitrogen than is accounted for by the amid compounds simply. The data afford no information by which we may judge whether the amids are entirely extracted in the "matiere noire" or not. If they are, the residual nitrogenous organic substances may be further sub-divided into two groups: That portion soluble as "matiere noire," and that part insoluble in the alkaline solvent.

It is observable, further, that the "matiere noire" from the limed soils is slightly richer in nitrogen than that from the magnesian treatment.

In general, the effect of both alkaline earths was to diminish the active humus, and the nitrogen, particularly that present as ammonia, and to increase the nitrates. While lime acted somewhat more vigorously than magnesia in the two particulars first named, there is no certain indication as to which was the more potent in favorably influencing the process of nitrification.

### *Effects of Liming upon the Character of the Vegetation Growing upon the Treated Soil.*

It has been a matter of almost universal remark in localities where liming is practised, that its use is followed by a very marked change in the character of the vegetation, particularly in the quality and kind of cultivated crops and forage plants that the soil produces.

The reports of correspondents from various portions of this State remark upon the greatly improved growth of forage plants, including the valuable grasses, but especially white and red clovers, after the application of lime; also, upon the disappearance of horse sorrel (red top," as it is called in some localities of the State) and of wild blackberries and dewberries.

Heinrich* notes the marked differentiation of the plants upon the same soil, on tracts that have been limed as compared with tracts not limed. He says: "In trials made upon a soil deficient in lime, one portion of which was limed, while another received a dressing of nitrate of soda, both receiving equal quantities of mixed clover and grass seed, the appearance was as though one part (that which was limed) had been seeded only with clover, the other only with grasses. Closer examination showed that both kinds of plants were present in each case, but that the plant most affected by the particular fertilizing materials used respectively crowded out the other plants. To secure a mixed forage it is, therefore, not enough to seed with a proper seed mixture, it is needful to see that the chemical composition of the soil is such as is adapted to the several plants."

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*Mergel u. Mergeln, 6.

Flagg, Wheeler and Tucker[*] separated the several portions of the hay cut from plats that had received different treatments, and that were laid out upon the upland, granitic sandy soil of the Rhode Island Station upon which sorrel grows luxuriantly; they obtained the following portions by weight from areas two feet square:

| Treatment. | Clover. | Sorrel. | Timothy. | Miscellaneous weeds. |
|---|---|---|---|---|
| | Lbs. | Lbs. | Lbs. | Lbs. |
| No nitrogen—limed, | 3.26 | 0.06 | 0.00 | Trace. |
| No nitrogen—unlimed, | 0.00 | 1.35 | Trace. | 0.05 |
| Dried blood—limed, | 3.00 | 1.00 | 0.09 | 0.00 |
| Dried blood—unlimed, | Trace. | 0.95 | 0.00 | 0.05 |
| Nitrate of soda—unlimed, | Trace. | 0.70 | Trace. | 0.00 |
| Sulfate of ammonia—unlimed, | 0.00 | 3.50 | 0.00 | Trace. |

The almost entire absence of timothy in all cases is rather surprising, but the good effect of liming upon the clover yield is well shown. The author says: "It appears probable that the chief value of lime in eradicating sorrel is attributable to the fact that it brings about physical and chemical soil conditions, one or the other or both of which, are so highly favorable to the growth of clover and many other agricultural plants that they are able to occupy the land, thereby preventing sorrel from gaining a foothold."

The writer has frequently observed a very striking growth of sorrel upon patches of land, the clover and timothy upon which have failed to make a catch, though in other seasons the same land shows very little sorrel, the season having favored a good stand of the grass instead.

Careful surveys of the several plats used in the rotation fertilizer experiments of the Pennsylvania Experiment Station have repeatedly shown the same phenomenon, and have further shown the predominance of clover over timothy on the plats receiving lime, ground limestone or land plaster as compared with those dressed with acidulated phosphates and nitrogen, the timothy predominating, however, on the latter.

Voelcker[†] says: "Every (British) farmer knows how essential lime is for the healthy growth of very kind of produce. On soils destitute of lime, most crops, and especially green crops, are subject to disease, and "root crops" are apt to fail altogether on such land, even if it has been liberally manured with dung or guano. Up to a certain stage, grain and roots grown under such conditions appear to thrive well, but as the season advances they sustain a check, and at harvest time yield a miserable return. The cure for such failures, which are not uncommon where poor sandy soils prevail, is a good dose of lime or marl, and then, and only then, dung or guano may be applied to the greatest advantage. The most liberal application of farm-yard manure of the best quality never produces so beneficial and lasting an effect on poor sandy soils as when they have been previously well marled or limed."

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[*] Rep. R. I. Agr. Exp. Sta., 1895, 196-199.

[†] Quoted by Storer, II, 147.

P. Pichard,[†] in reference to the sandy soils of Brittany which are rich in humus but poor in lime and potash, says: "The application of lime raised the yield of fodder beets from 6,315 kilograms to 21,627 and 38,700 kilograms per hectare, or, in other words, the yield was quadrupled and sextupled. An addition of plaster still further increased the yield."

Dehérain[‡] says: "There are certain of the principal field crops, notably the legumes, which are so highly benefitted by the presence of lime that liming alone on grass lands, where calcareous matter is deficient, is all that is needful to secure a spontaneous growth of clover, the seeds brought there by the wind prospering as soon as the soil is made favorable to it."

"Limousin had been for ages a miserable land, and it was not transformed nor brought to the state of relative prosperity which it now enjoys until the time when the construction of a railroad allowed the introduction, at low cost, of lime from the Departement du Cher; the culture of clover, unknown until now in this granitic country, has become possible, more numerous and better fed domestic animals now supply enough manure to convert the thin pastures into productive grass lands; the food for an excellent race of Limousin beef being assured, its breeding has made rapid progress and the sale of the young animals has become a source of large profit to both land owners and tenants."

"In moist grass lands the use of lime has a remarkable effect; I have more than doubled the yield from the grass lands of l'Avre, belonging to the city of Paris, by treating them with lime or plaster, in addition to a small quantity of nitrate of soda."

Heinrich[§] says: "Potatoes and rye grow well even when the soil is too poor in lime for other crops. Large yields may still be obtained from soils, particularly when they are well cultivated, even though their lime content has fallen to 0.05 per cent."

"Oats and barley have a somewhat higher lime requirement than rye and potatoes."

"Peas and vetches grow quite well upon a soil having 0.10 per cent., but fail entirely upon poorer soil."

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[*] Mergel u. Mergeln, 7.

[†] C. R., 119, 473.

[‡] Traité, 531.

[§] Mergel u. Mergeln, 7.

"Red clover yields well with 0.1 to 0.12 per cent.; with less than 0.1 per cent., it fails completely, and yields best when the soil contains at least 0.2 per cent. of lime."

"Of all crops, alfalfa responds best to lime."

On the other hand, he says:† "Lime as calcium carbonate injuriously affects the growth of lupins when it is present to the amount of 0.46 per cent."

Wheeler and Tucker‡ have conducted, for several years, comparative tests of the growth of a great variety of plants upon soils receiving each year a basal mixture of dissolved bone-black, muriate of potash and nitrate of soda, and, in 1895 and 1896, 200 lbs. per acre of sulfate of magnesia; part receiving no lime, the rest 5,400 lbs. per acre in 1893, 1,000 lbs. per acre in 1894, none in 1895. The relative yields from the limed soil for the several years are given below, the corresponding yield on the unlimed soil being taken as 1:

Yields of Various Plants after Liming.

| | 1893. | 1894. | 1895. | 1896 |
|---|---|---|---|---|
| Grasses. | | | | |
| Awnless Brome Grass, | | | 1.55 | 1.21 |
| Kentucky Blue Grass, | | | 1.20 | 1.21 |
| Meadow Fox-tail, | | | 1.30 | |
| Meadow Oat Grass, | | | 1.09 | 1.16 |
| Orchard Grass, | | | 1.16 | |
| Red Top, | | | 1.17 | 0.94 |
| Rhode Island Bent, | | | 0.99 | 1.18 |
| Sheep's Fescue, | | | 0.00 | 1.51 |
| Soft Grass, | | | 1.01 | 1.17 |
| Sweet Vernal, | | | 0.89 | |
| Tall Fescue, | | | 1.24 | |
| Timothy, | | | | 1.22 |
| Leguminous Forage Crops. | | | | |
| Alfalfa (1st crop), | | | 3.68 | |
| Alfalfa (2d crop), | | | 1.49 | |
| Bean, Soja, | | 1.06 | | |
| Bean, White Podded Adzuki, | 0.82 | 0.88 | | |
| Blue Lupine, | 0.47 | 0.23 | 0.61 | 0.77 |
| Cow Pea, | 0.80 | 0.94 | | |
| Clover, Crimson, | 1.35 | | | 1.59 |
| Clover, Red, | | 1.70 | | |
| Serradella, | | | 0.69 | |
| Millets. | | | | |
| Panicum cruss-galli, | 1.31 | | 0.82 | |
| Golden, | 1.04 | 0.87 | | |
| Hungarian, | 0.91 | | | |
| Italian, | 0.87 | | | |
| German, | | 0.90 | | |

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†*Op. cit.*, 63.

‡R. I. Agrl. Exp. Sta., Bulletin 46, pp. 97-100.

### Yields of Various Plants after Liming—Continued.

| | 1893. | 1894. | 1895. | 1896 |
|---|---|---|---|---|
| **Grains.** | | | | |
| Barley, | 1.80 | 2.06 | 3.58 | 2.56 |
| Buckwheat, | 1.65 | 1.53 | ............ | ............ |
| Corn, Dent, | 1.17 | ............ | ............ | ............ |
| Corn, White-capped, | 0.71 | ............ | ............ | ............ |
| Corn, Pop, | 1.56 | ............ | 1.03 | ............ |
| Corn, Sweet, | 2.07 | 1.11 | 1.89 | ............ |
| Corn, Field, | ............ | 0.61 | 1.06 | ............ |
| Oats, | 1.26 | 1.09 | 1.07 | ............ |
| Rye, Spring, | 1.13 | 1.08 | 0.75 | 1.33 |
| Wheat, Spring, | ............ | 1.40 | 1.91 | ............ |
| **Vegetables.** | | | | |
| Bean, Common White, | 0.94 | 0.88 | ............ | ............ |
| Bean, Golden Wax, | ............ | 1.58 | ............ | ............ |
| Beet, French Sugar, | 12.17 | 11.00 | ............ | ............ |
| Beet, Golden Tankard, | 10.75 | ............ | ............ | ............ |
| Beet, Eclipse Table, | 7.78 | 5.35 | 1.84 | ............ |
| Beet, Mangel, Long Red, | 7.59 | 5.77 | ............ | ............ |
| Beet, Mangel, Globe, | ............ | 8.21 | ............ | ............ |
| Beet, Mangel, | ............ | ............ | 4.95 | 5.73 |
| Brussels Sprouts, | ............ | 1.57 | ............ | ............ |
| Cabbage, Late, | 2.37 | 4.60 | 1.70 | ............ |
| Cabbage, Early, | 1.28 | 1.24 | ............ | ............ |
| Carrot, Victoria, | 1.78 | ............ | ............ | ............ |
| Carrot, Mastodon, | 1.76 | ............ | ............ | ............ |
| Carrot, Long Orange, | ............ | 0.87 | ............ | ............ |
| Carrot, Danvers, | ............ | 0.74 | ............ | ............ |
| Carrot, White, | ............ | 1.18 | ............ | ............ |
| Carrot, | ............ | ............ | 1.96 | 0.67 |
| Cauliflower, | ............ | 3.70 | ............ | ............ |
| Celery, | ............ | 9.42 | 27.60 | ............ |
| Cucumber, | ............ | 3.02 | ............ | ............ |
| Dandelion, | ............ | 1.08 | 1.74 | 2.83 |
| Egg Plant, | ............ | 3.75 | ............ | ............ |
| Gumbo, | ............ | 11.38 | ............ | ............ |
| Kale, | 1.51 | 1.15 | ............ | ............ |
| Kohl Rabi, | ............ | 1.59 | 1.60 | ............ |
| Lettuce, | 77.93 | 10.00 | ............ | ............ |
| Martynia, | ............ | 2.84 | ............ | ............ |
| Muskmelon, | ............ | 4.70 | 2.45 | ............ |
| Onion, Red, | ............ | 9.00 | ............ | ............ |
| Onion, Yellow, | ............ | 8.12 | ............ | ............ |
| Onion, Barletta, | ............ | 7.88 | ............ | ............ |
| Onion, Egyptian, | ............ | 31.00 | ............ | ............ |
| Parsnep, | ............ | 6.99 | ............ | ............ |
| Pea, Granger, | 1.53 | ............ | ............ | ............ |
| Pea, Garden, | ............ | 1.65 | ............ | ............ |
| Peanut, | ............ | 2.53 | ............ | ............ |
| Pepper, | ............ | 3.74 | ............ | ............ |
| Potato, Early Rose, | 1.03 | 1.05 | ............ | ............ |
| Potato, Beauty of Hebron, | ............ | 1.67 | ............ | ............ |
| Pumpkin, | ............ | 0.55 | 5.36 | ............ |
| Radish, Long Scarlet, | ............ | 1.37 | ............ | ............ |
| Radish, French Breakfast, | ............ | 0.87 | ............ | ............ |
| Salsify, | ............ | 9.50 | ............ | ............ |
| Spinach, | 24.75 | 61.00 | ............ | 20.50 |
| Tomato, | 1.40 | 1.42 | ............ | ............ |
| Turnip, Ruta Baga, | 1.58 | 1.46 | ............ | ............ |
| Turnip, Purple Top, | ............ | 1.29 | ............ | ............ |
| Turnip, Early Red Top, | ............ | 1.15 | ............ | ............ |
| Turnip, Flat, | ............ | ............ | 1.34 | ............ |
| Watermelon, | ............ | 0.64 | 0.55 | ............ |
| **Miscellaneous Plants.** | | | | |
| Gladiolus, | ............ | ............ | ............ | 0.87 |
| Jerusalem Corn, | 2.41 | ............ | ............ | ............ |
| Kaffir Corn, | 3.40 | ............ | ............ | ............ |
| Rape, | ............ | 1.97 | ............ | ............ |
| Sorghum, | 10.59 | 2.99 | ............ | ............ |
| Sorrel, | ............ | 0.36 | 0.82 | ............ |
| Sunflower, | 1.09 | 1.42 | ............ | ............ |
| Tobacco, | ............ | 4.52 | ............ | ............ |

Almost without exception the grasses have shown benefit from liming; among the millets, in only two cases out of seven; among the grains, barley, buckwheat and wheat have shown much more benefit than corn (with a curious exception in the case of sweet corn), oats or rye; among the leguminous forage crops there is a very strange contrast, already noted by Heinrich and others: while the clovers and alfalfa exhibit a very marked advantage from liming, the soja bean shows none and the blue lupine, serradella, cow pea and white podded adzuki bean show most marked injury. Among the vegetables there was a very general improvement, except in the case of the watermelon and of some specimens of pumpkin, carrot and radish; beets, celery, gumbo, lettuce, onions and spinach were most advantageously affected. Among miscellaneous plants, sorghum and tobacco were most favorably, horse sorrel and the gladiolus unfavorably affected.

Salfeld[*] and Wheeler[†] incline to the opinion that the injury to the lupine and other legumes is not direct, but rather upon the minute organisms forming the nodules on the roots of such plants.

### *Influence upon Insects and Injurious Fungi.*

Concerning its influence on hurtful insects and fungi, Storer[‡] says: "Slaked lime is regarded as a cure for some hurtful fungi. The liming of seed grain to destroy the fungus which causes 'rust,' or 'smut,' has long been usual. The use of lime upon turnips, as check to the finger-and-toe disease has been mentioned; and I can myself bear witness that I have grown exceptionally fair and smooth rutabagas during three consecutive years upon limed land at the Bussey Institution, though no farmer in the vicinity would venture to try to grow turnips year after year on any one field, because of their liability to the disease called 'club foot.' * * It is not improbable * * * that some part of the good done by the lime may be due to the destruction of insects and their larvae, as well as earth-worms and worms of other kinds, and fungi of various sorts. Indeed, lime-water, lime and mixtures of lime and salt (or, better yet, of lime and muriate of potash) are often purposely used by gardeners for destroying slugs and worms; and there are good reasons for believing that lime might often be applied to the soil with advantage in farming practice also on this account."

The voluminous literature of the American Experiment Stations gives many observations in confirmation of Storer's opinion, though lime cannot be regarded as an universally applicable remedy. It absolutely favors the potato scab fungus, and potatoes grown on limed soil from scabby seed are usually very greatly roughened by the exceptional growth of the scab under such conditions.

### *Lime Supposed to Act Chiefly as Carbonate:*

Does the lime act in the soil in the caustic or in the carbonated form?

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[*] Die Boden Impfung, pp. 79-83.

[†] Bull. 46, R. I. Exp. Sta., 93.

[‡] *Op. cit.*, II, 147-8.

There is considerable doubt upon this question. Recognizing the general tendency of lime to take up carbonic acid promptly by the process of air-slaking and considering the fine sub-division of the slaked lime as it reaches the soil, and the facts that the air of the soil is commonly much richer in carbonic acid than is the general atmosphere and that the fermentative destruction to which the humus and other organic matters of the soil are increasingly subjected through the influence of the added lime, must temporarily tend to a still greater proportion of carbonic acid in the soil air, it is generally conceded that the lime must be carbonated almost immediately after it is spread and harrowed in.

Storer* says: "It is not to be supposed that, in the field, reactions due to the causticity of the lime can go on for any long period." He then gives reasons, similar to those of the preceding paragraph, for this belief. "The action of the carbonate of lime, when formed, will not differ essentially from that of marl, or powdered limestone."

Mayer† also makes a very similar statement.

Influence of Fineness of Carbonate:

R. Heinrich,‡ going upon the above theory, claims that the lime changes almost immediately after its application to the soil, to the carbonate; the greater effect of burnt lime, as compared with pulverized chalk, limestone and other lime carbonates, is supposed to be due not to its causticity, but to the finer sub-division of the carbonate which is formed from it. To show the influence of fineness upon the effective action of calcium carbonate, this investigator grew peas and alfalfa in a series of pots; the sandy soil used contained only 0.091 per cent. of lime; the pots in most of the series received a basal manure containing potash and phosphoric acid, and four sets received a further addition of finely pulverized Carrara marble, of different degrees of fineness, graded by sifting, the quantity added in each instance being equal to 0.5 per cent. of the weight of the soil. Letting the maximum yield be represented by 100, the several crop yields were relatively as follows:

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*Op. cit., II, 151.
†Lehrb. Agr. Chem., II, 286.
‡Mergel u. Mergeln, 29.

| Treatment. | Peas. | Alfafa. |
|---|---|---|
| Unfertilized, | 54.2 | 0 |
| Basal fertilizer alone, | 47.1 | 0 |
| Fertilizer and marble, grains 1.5 to 2 mm. diameter, | 66.7 | 59.2 |
| Fertilizer and marble, grains 1.0 to 1.5 mm. diameter, | 80.1 | 78.5 |
| Fertilizer and marble, grains 0.5 to 1.0 mm. diameter, | 90.2 | 100.0 |
| Fertilizer and marble, grains less than 0.5 mm. diameter, | 100.0 | 100.0 |

In other words, the carbonate in grains of 0.06 to 0.08 inches diameter, was scarcely more than half as efficient as that of about half that diameter, the surface exposed to the action of solvents being four times greater in the latter case, assuming an equal distribution of the particles in each instance.

A. Bernard[*] suggests that the efficiency of the lime compound depends not solely upon its nature and fineness of sub-division, but also upon the relation between its effective surface and that of other soil constituents present; thus clay, being more finely divided than sand, would more largely modify the action of the lime than would sand.

Comparative Effects of Caustic and Carbonated Lime:

It is further asserted that in many ways the actions of the caustic lime and the carbonate are almost precisely alike.

Thus, to test their relative efficiency in liberating alkalies from a soil, Heinrich[†] exposed 200 grammes of soil and of mixtures of the soil with caustic lime and calcium carbonate in quantities equivalent to 0.5 per cent. of calcium oxid for each 100 parts of soil. Water to the amount of 750 c. c. was used, and where carbonic acid was employed it was led into the liquid, already mixed with the soil, for one hour at the beginning of the period of twenty-four hours, during which the solvent acted in each case. The results are expressed in the weight of alkaline sulfates found in the liquid for each 100 grammes of soil used:

| Treatment. | Weight of alkaline sulfate. Grammes. |
|---|---|
| 1. Pure water, | 0.031 |
| 2. Pure water with carbonic acid, | 0.038 |
| 3. Pure water with caustic lime, | 0.048 |
| 4. Pure water with caustic lime and carbonic acid, | 0.066 |
| 5. Pure water with carbonate of lime, | 0.046 |
| 6. Pure water with carbonate of lime and carbonic acid, | 0.060 |

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[*] Le Calcaire, 59-62.

[†] *Op. cit.*, 29.

That is, the caustic lime and the carbonate were of equal effectiveness under like conditions of action.

Dietrich* had, much earlier, made a similar investigation, exposing soils and pulverized rocks for three months to the action of distilled water with (1) caustic lime, (2) calcium carbonate, (3) calcium carbonate and carbonic acid. Two hundred grammes of the material, from which readily soluble matter had first been removed by repeated washing, were used with 150 c. c. of water; the lime used equalled 1 per cent. of the soil, the calcium carbonate 2 per cent. The carbonic acid was added to saturation and four times renewed during the experiment. The alkalies made soluble are expressed as chlorids, in grammes:

| Material. | Caustic lime. | Calcium carbonate. | Calcium carbonate and carbonic acid. |
|---|---|---|---|
| | Grammes. | Grammes. | Grammes. |
| Basalt, freshly broken, moderately fine, | 0.144 | 0.057 | 0.154 |
| Porphyry, | 0.009 | Trace. | 0.011 |
| Loam rich in humus, | 0.022 | 0.014 | 0.023 |
| Loam rich in humus, burned, | 0.024 | 0.029 | 0.025 |

In this experiment, the carbonate was markedly inferior, except in case of the burned loam; with the aid of carbonic acid, however, its action was equal to that of the caustic lime. There is no satisfactory information concerning the fineness of the carbonate, however, so that the inferior action of the latter may be due to its coarseness rather than to its chemical inactivity.

The sulfate is said to be more potent than caustic lime in converting anhydrous silicates to the more available forms.

It has already been observed that the mild carbonate of lime is readily attacked by humus acids, so that it serves well the purpose of correcting soil acidity; also, that it more favorably affects nitrification than does caustic lime; and, very possibly, the same may be true of the other bacterial actions constantly occurring in the soil. Furthermore, if, as some aver, the flocculating action of lime be really due to a solution of acid calcium carbonate, the carbonate should equally well promote the improvement of heavy clay soils.

To secure more direct testimony as to the eventual net result of the various reactions set up in the soil by the application of lime in the caustic or the carbonated condition, Henirich† carried on an experiment, using the same soil and basal manure as were employed by him in the previously described experiment made to determine the influence of the fineness of the carbonate upon its efficiency. In addition to the basal manure, enough of the several calcareous compounds was added to furnish calcium oxid equivalent to 0.5 per cent. of the soil. The relative weight of peas and alfalfa secured are given below, 100 standing for the maximum:

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*J. prak. Chem., 74, 12; Jb. Agr. Chem., 1, 34.

†*Op. cit.*, 23.

| Treatment. | Peas. | Alfafa. |
|---|---|---|
| 1. No fertilizer, | 47 | 0 |
| 2. Basal fertilizer, | 41 | 0 |
| 3. Marly loam from Lupitz (contains 8.46 per cent. lime), | 79 | 97 |
| 4. Commercial precipitated shells (contains 54.39 per cent lime), | 100 | 73 |
| 5. Wiesenkalk (contains 32.14 per cent. lime), used in fresh, soft state, | 96 | 100 |
| 6. Caustic lime, powder, prepared from marble, | 98 | 79 |
| 7. Chalk lime (Lüneborg manure), (51 per cent. lime), | 98 | 80 |
| 8. Coral chalk (54.9 per cent. lime in dry substance), | 84 | 84 |
| 9. White Carrara marble, | 88 | 87 |
| 10. Precipitated chalk from sugar factory, | ............... | 86 |

The carbonates were finely powdered and passed through a very fine sieve before application.

In both cases higher results were obtained from certain carbonates than from the caustic limes.

On the other hand, the caustic action of lime as a fungicide or vermicide, can not be performed by the carbonate. Laboratory experiments also indicate a far less vigorous direct chemical action by the carbonate than by the caustic compound in decomposing organic matters.

General experience, especially upon heavy soils, leads to a decided preference for the burnt lime. Loudon* says: "The effect of powdered limestones * * * as a manure * * * is so much inferior to that of burnt lime that they have long since been laid aside."

But this may be due solely to the fact that it is not practicable to secure by purely mechanical means so fine a state of sub-division as that which is attained by burning and slaking.

Lime in Mass Not Completely Carbonated:

Reasoning by analogy from the rate at which lime air-slakes in the heap, it is almost necessary to assume that lime can not long remain caustic after it has been spread and worked into the soil in a finely divided state. It is true, though, that compact lumps or masses of calcium hydrate, once their surfaces are carbonated, change very slowly through their interior portions. Thus, Reid states that upon examining mortar used several centuries since in the construction of certain European buildings, the interior portions of the mortar were found to exist, even yet, in an uncarbonated, caustic condition.

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*Encyclopedia of Agriculture, § 887.

Condition of Lime and Magnesia in Treated Soils Under Experiment:

To secure direct evidence upon the state of combination of the lime and magnesia at the end of the experiments made in our laboratory and to further examine into the allegation that magnesium lime may owe its sometimes injurious action to the slower rate of its carbonatation, a careful determination of the amounts of carbonic acid present in the soils treated with lime and magnesia was made by Mr. C. W. Norris by the method previously used upon the original soils. The results were as follows:

TABLE XV—Percentage of Carbonic Acid in Treated Soils.

| Soils. | Lime treatment. | Magnesia treatment. |
|---|---|---|
| I, | 0.207 | 0.094 |
| II, | 0.163 | 0.046 |
| III, | 0.235 | 0.005 |
| IV, | 0.116 | 0.260 |
| V, | 0.110 | 0.020 |
| VI, | 0.089 | 0.030 |
| VII, | 0.202 | 0.063 |
| VIII, | 0.135 | 0.015 |
| IX, | 0.133 | 0.045 |

Using these percentages and those obtained for the original soils, and correcting for the differences in soil moisture, but neglecting, as inconsiderable, any changes in weight the soils might have undergone from other causes, the percentages of the added lime and magnesia that had become converted to carbonates by the end of the experiment are estimated to be as follows:

TABLE XVI—Percentage of Alkaline Earths Carbonated in the Soil.

| Soils. | Lime treatment. | Magnesia treatment. |
|---|---|---|
| I. | 48.8 | 15.1 |
| II. | 31.7 | 1.8 |
| III. | 50.9 | 15.3 |
| IV. | 18.2 | 56.9 |
| V. | 21.7 | * |
| VI. | * | * |
| VII. | 41.5 | 7.5 |
| VIII. | 26.6 | * |
| IX. | 21.5 | * |

In those cases marked with a star, less carbonic acid was found at the end than at the beginning of the experiment. After ten months in thorough admixture with soils more or less supplied with humus, less than half the lime had combined with carbonic acid, in all but one soil. In the muck soil there was no more carbonic acid than at the outstart.

Concerning the conditions of these experiments it may be remarked that the lime did not lie exposed upon the surface of the soil for any length of time, nor was the contact of the soil with carbonic acid from the air so complete as would be the case in an open field. On the other hand, however, the lime was very finely sub-divided and well distributed through soils in which there was considerable decay of humus during the progress of the experiment, such as is supposed to furnish carbonic acid in abundance.

The evidence favors the belief that the conversion of caustic lime to carbonate in the soil may be much less rapid than has been heretofore assumed. It does not. however, show positively the state of combination in which the uncarbonated lime exists. Some of it is doubtless affiliated with the silicates, humates or ulmates, nitrates and phosphates of the soil, but considering the relatively large quantity applied, it is difficult to conceive that a very large fraction has not remained in caustic condition.

Magnesia Less Readily Carbonated:

As for the magnesia, it evidently carbonates much less readily than the lime, and the inference that the evil effects sometimes observed after its application in magnesian limes, may be due to its persistent causticity, is strongly supported.

## SUMMARY OF RESULTS OF THE PENNSYLVANIA EXPERIMENTS.

1. Most of the soils contained a moderate amount of lime, only two being strikingly deficient.

2. All but one contained more magnesia than lime.

3. No effect upon the moisture relations followed the use of lime. Very probably the failure to discover such effect is due to a faulty preparation of the soil for observation.

4. Liming was, in all cases, followed by increased availability of the potash, sometimes to nearly 50 per cent. of the original amount available.

5. A similar increase in available phosphoric acid accurred in all but one soil.

6. In four of the soils acidity was evident, so that some of the benefit derived in practice from liming these soils is attributable to the neutralization of the acid.

7. There was less loss of total organic matter, but more loss of active humus as the result of liming compared with fallowing.

8. Liming resulted in a diminution of the nitrogen, from loss of ammonia in all probability; a marked increase in nitrates and, in one soil, of nitrogen in other organic compounds than the amids. The nitrogen in the form of amids, in one soil, and of active humus suffered a decided decrease.

9. At the end of ten months, much less than 50 per cent., on the average, of the added lime had turned to carbonate.

10. As for the magnesia, it liberated potash as freely as did lime, on the average; was even more influential than lime in its average effect in rendering the phosphoric acid more assimilable; an even smaller quantity would suffice of magnesia than of lime as a corrective of acidity; it affected total organic matter and *matiere noire* in manner and degree like lime, as also it did the various nitrogenous compounds, except that ammonia was more abundant in its presence. It carbonated very much less readily than lime.

So that, in general, its functions in the soil are very similar to those of lime. It is only when it is applied in large quantity so that it may keep the soil too highly alkaline for a long period or may, in some other manner, act poisonously upon the plant in the absence of a proper proportion of lime, that ground is given for objection to its use. Moderate applications of most of the magnesian limes of Pennsylvania can be made without fear when liming is indicated as desirable.

## VII. THE PRACTICE OF LIMING.

### CIRCUMSTANCES SUGGESTING THE USE OF LIME.

It is not possible to indicate certainly all cases in which liming is admissible. Its use is clearly suggested as needful, sooner or later, upon light uplands whose characteristic vegetation shows that lime is not abundant; when soils are acid, whether from the oxidation of sulfids, from the residues of fertilizers or from humus; when clay soils become too adhesive; when swamp lands are to be brought rapidly into bearing (in both these last named cases, draining must precede liming to secure the full efficiency of the latter). It will be helpful when heavy sod, a large green-manuring crop or a heavy dressing of very strawy manure is to be turned under, especially in a soil deficient in lime or magnesia; in these cases a good distribution of the lime in contact with the decaying vegetable matter should, in one way or another, be secured. When clover persistently fails, a moderate liming is suggested as a possible necessity before securing a good growth. It is clearly indicated on lands where turnips suffer from the "finger-and-toe" disease, but should be avoided where potatoes are to follow soon in the rotation. Where lime is cheap, it may prove, for a time, the cheapest means of securing available potash, by its action upon the unavailable supply already present in the soil. On soils relatively rich in iron and requiring the use of phosphatic fertilizers, a moderate dressing of lime before the time of fertilizing will greatly increase the duration of effect of the phosphate.

On the other hand, liming alone is insufficient on poor lands; they may respond well for a brief time, but are soon exhausted of the materials upon which lime can react. On such lands, heavy manuring must go hand in hand with liming. Indeed, even on lands of good heart, care must be taken to maintain the humus supply when liming is constantly practised.

### FREQUENCY OF LIMING.

As to the frequency of liming, circumstances must somewhat determine. A single heavy dressing of lime may correct the undue plasticity of a clay and retain it in a flocculated condition for many years, particularly when it is tilled with judgment; later, light dressings applied at not too great interval, will suffice to retain the desirable texture indefinitely. For the correction of acidity a single heavy dressing may suffice for years. Where, however, the immediate breaking down of vegetable matter is desired, an application, at the time, of a properly adjusted quantity of lime would seem advisable.

## QUANTITY TO BE APPLIED.

As to the quantity of lime applied: this must depend upon the frequency of the application, as well as upon the purpose sought to be accomplished. In correcting the plasticity of a heavy clay, or the acidity of a soil, or in preparing new land, rich in humus, for some intensive culture such as onion growing or celery, the first dressing may need to be heavy. An application of upwards of 100 bushels of slaked lime would doubtless prove economical in a few such cases. Good results have attended the use, in such circumstances, of as much as 500 bushels of slaked lime; but it is rare that better growth is observed where the lime was thickly spread, near the heap or wagon, than where it lies more thinly upon the ground at the points more remote from the center of distribution. In general, it would be wise to prove by actual test that more than 100 bushels actually gives a paying result over and above that yielded by the smaller dressing, before going to the expense of the heavier application. As lime does not retain its maximum efficiency for a very long time, as it is among the substances more easily removed from the soil by drainage and, particularly, as it tends to pass quickly into the sub-soil while its effects are chiefly sought in the surface soil, lighter dressings at more frequent intervals are more likely to produce an economical result than very heavy dressings at longer intervals. Indeed, it may safely be stated as a rule applicable to most cases, that when the soil has already been brought into fair condition, an application of fifty bushels or even less will suffice to maintain heavy lands in good tilth and fertility if made once in six to ten years. On lighter soils, under like conditions otherwise, the dressing may often show its maximum benefit if no greater than twenty-five bushels. For light lands especially, is the maxim of very light dressings made more frequently, to be adopted. The dressing should be larger, the deeper the surface soil.

## WHEN TO LIME.

For special purposes, the time for liming indicates itself—as in correcting some injurious condition of the soil, such as adhesiveness or acidity, or as in the preparation of new land for use, or as in the top dressing of a permanent meadow when clovers are failing.

But some plants, as Wheeler* has remarked, are especially liable to injury from the effect of caustic lime, and its use just before their planting is not commendable unless circumstances compel it; such crops are Indian corn, rye and millet. On the other hand, certain crops, such as beets, lettuce, spinach, celery, cauliflower, kohl rabi, onions, muskmelon, cantaloupes, salsify, cabbages, cucumbers, etc., seem to thrive especially well immediately after a liming. For the general purpose of maintaining in the soil an adequate supply of calcium carbonate, with all its attendant advantages and, at the same time, of gaining the maximum immediate advantage upon that crop in our general rotations that most fully responds to lime, it is believed that the use of a small quantity when seeding down or, in some ways even better, as a top dressing upon the clover in wheat or oats stubble, will give the largest return.

### PREPARATION OF LIME.

The precautions that should be taken to keep the lime in a caustic state and to secure its proper slaking have already been stated with the reasons therefor. It only needs to be added that the lime should be worked thoroughly into the surface soil as soon as it is spread, except when it is to be plowed under with sod, green or stable manure, or when, of course, it is added as a top dressing to a growing crop.

### METHOD OF APPLICATION.

When used before corn, it is commonly better to apply in the fall or winter, if spring plowing is adopted, and the plowing is shallow. In this way, the best return to the crop is often secured. If, however, the plowing is deep, better results have often attended the use of lime as a top dressing harrowed in some days before corn planting. There is some reason for believing that where the sod is very heavy, and is to be deep plowed, a division of the application, part upon the sod, and part, later, as a top dressing, would be more beneficial. The various means of distribution have been earlier discussed.

### LIME SUBSTITUTES.

Where lime is not readily accessible, carbonate of lime is sometimes to be had in the form of leached wood ashes, tannery ashes or marl. The quantity to be applied must vary with the composition.

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*Bulletin 46, R. I. Agr. Exp. Sta., p. 94.

It requires nearly twice as much carbonate as of pure, unslaked quicklime to perform a given work; often much more, from the fact that the ash, marl, etc., are much coarser grained.

Unleached wood ashes require some caution when used in large quantities. The considerable quantities of potassium carbonate they contain, often more than neutralize the flocculating effect of the calcium carbonate and leave a heavy soil even more adhesive and compact than before the application of the ash; but they are more efficient than lime in compacting very light soils.

# APPENDIX A.

## I.—LIST OF FARM CORRESPONDENTS—BY COUNTIES.

| | |
|---|---|
| Adams, | Mr. L. W. Lighty, East Berlin. |
| | Mr. Geo. P. Myers, Flora Dale. |
| Armstrong, | Mr. S. S. Blyholder, Leechburg. |
| | Mr. A. M. Hindman, Craigsville. |
| Beaver, | Mr. Wm. T. Anderson, New Galilee. |
| Bedford, | Hon. J. S. Biddle, Loysburg. |
| | Mr. G. W. Oster, Osterburg. |
| | Mr. Thomas P. Beckley, Alum Bank. |
| Berks, | Hon. George D. Stitzel, Reading. |
| | Mr. J. W. Albright, Shartlesville. |
| Blair, | Mr. Frederick Jaekel, Hollidaysburg. |
| Bradford, | Mr. S. W. Lester, Troy. |
| | Mr. Asa S, Stevens, Franklindale. |
| Bucks, | Mr. John K. Scarborough, Pineville. |
| | Mr. Ezra Michener, Carversville. |
| | Mr. F. L. Mulford, Edgewood. |
| Butler, | Mr. Harlan Book, Euclid. |
| | Mr. O. W. Stoughton, Prospect. |
| Cambria, | Mr. David B. Wertz, Johnstown. |
| | Mr. John E. Tomlinson, Loretto. |
| Cameron, | Mr. E. M. Fairchild, Sizerville. |
| | Mr. B. V. Wykoff, Sinnemahoning. |
| Carbon, | Mr. George T. Wells, Rockport. |
| Centre, | Mr. T. M. Gramley, Spring Mills. |
| | Col. J. F. Weaver, Milesburg. |
| Chester, | Mr. R. M. Simmers, Phoenixville. |
| Clinton, | Mr. Joel A. Herr, Cedar Springs. |
| Columbia, | Mr. A. P. Young, Millville. |
| | Mr. Albert Cope, Berwick. |
| | Hon. William T. Creasy, Catawissa. |
| Crawford, | Mr. John C. McClintock, Meadville. |
| Cumberland, | Hon. S. M. Wherry, Shippensburg. |
| | Mr. B. D. Biggs, Shippensburg. |
| Dauphin, | Mr. S. F. Barber, Harrisburg. |
| | Mr. John Moyer, Gratz. |
| | Mr. Gabriel Hiester, Harrisburg. |

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|---|---|
| Delaware, | Mr. Joseph H. Paschall, Ward. |
| | Mr. William M. Ott, Station M, Philadelphia. |
| Elk, | Mr. J. M. Wittman, St. Marys. |
| | Mr. Joseph Kaiser, St. Marys. |
| Erie, | Mr. H. H. Russell, Belle Valley. |
| | Hon. H. H. Chaffee, Lowville. |
| | Mr. B. J. Crowell, Lovell's Station. |
| Fayette, | Mr. W. E. Crawford, Belle Vernon. |
| Forest, | Mr. C. A. Randall, Tionesta. |
| | Mr. T. D. Collins, Nebraska. |
| Franklin, | Mr. Henry Omwake, Greencastle. |
| | Mr. C. B. Hege, Marion. |
| | Dr. A. H. Strickler, Waynesboro. |
| Fulton, | Mr. J. F. Johnston, Webster Mills. |
| | Hon. S. P. Wishart, Wells' Tannery. |
| Greene, | Mr. N. H. Biddle, Carmichaels. |
| Huntingdon, | Mr. George G. Hutchison, Warrior's Mark. |
| | Mr. T. O. Milliken, Cornpropst's Mills. |
| | Dr. W. T. Browning, Orbisonia. |
| Indiana, | Hon. N. Seanor, Denton. |
| | Hon. John Hill, Blairsville. |
| Jefferson, | Mr. James McCracken, Frostburg. |
| | Mr. John H. Lewis, Frostburg. |
| Juniata, | Mr. J. T. Ailman, Thompsontown. |
| | Mr. D. B. McWilliams, Walnut. |
| Lackawanna, | Mr. J. H. Hathrill, Moscow. |
| Lancaster, | Capt. J. P. Bricker, Lititz. |
| | Mr. James Collins, Quarryville. |
| Lawrence, | Mr. George Dean, Princeton. |
| | Mr. Thomas Love, Hillsville. |
| Lebanon, | Mr. Samuel Groh, Lickdale. |
| Lehigh, | Mr. Alfred J. S. Diefenderfer, South White Hall. |
| | Mr. P. P. Mohr, Fogelsville. |
| Luzerne, | Mr. John R. Gould, Bell Bend. |
| | Mr. William J. Honeywell, Dallas. |
| | Mr. H. B. Larned, Huntingdon Mills. |
| Lycoming, | Mr. Abner Fague, Picture Rocks. |
| | Mr. R. H. Grier, Jersey Shore. |
| | Hon. A. J. Kahler, Hughesville. |
| McKean, | Mr. Eugene Mullin, Bradford. |
| | Dr. A. B. Armstrong, Smethport. |
| | Mr. T. M. McClellan, Mt. Jewett. |
| Mercer, | Mr. J. C. Mossford, Millbrook. |
| Mifflin, | Mr. R. A. Naginey, Milroy. |

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|---|---|
| Monroe, | Mr. Emil Ulrich, Stroudsburg. |
| | Mr. Randall Bisbing, Minsi. |
| | Hon. R. F. Schwarz, Analomink. |
| Montgomery, | Hon. Jason Sexton, Spring House. |
| Northampton, | Hon. B. B. McClure, Bath. |
| | Mr. W. M. Benniger, Walnutport. |
| | Mr. Albin F. Meyer, Moorestown. |
| Northumberland, | Mr. C. N. Marsh, Pottsgrove. |
| | Mr. B. F. Reitz, Elysburg. |
| Perry, | Mr. C. L. Steele, Duncannon. |
| | Mr. George S. Barnett, New Bloomfield. |
| | Mr. James E. Stephens, Acker. |
| Philadelphia, | Mr. J. B. Kirkbride, Bustleton. |
| Pike, | Mr. J. H. VanEtten, Milford. |
| Potter, | Mr. W. A. Gardner, Andrews' Settlement. |
| | Mr. John McDowell, Pleasant Valley. |
| Schuylkill, | Mr. W. H. Stout, Pine Grove. |
| | Mr. W. H. Riland, Friedensburg. |
| Snyder, | Mr. M. K. Hassinger, Middleburg. |
| | Mr. Jacob H. Hetrick, Beavertown. |
| Somerset, | Hon. N. B. Critchfield, Critchfield. |
| | Mr. C. S. Beal, Elklick. |
| Susquehanna, | Mr. E. W. Watson, New Milford. |
| Tioga, | Mr. F. E. Field, Balsam. |
| | Mr. Homer Wilson, Mansfield. |
| | Mr. W. W. Inscho, Canoe Camp. |
| | Mr. William Norman, Sebring. |
| Union, | Mr. R. J. Moyer, White Deer. |
| | Mr. H. G. McCarty, Spring Garden. |
| | Mr. John A. Gundy, Lewisburg. |
| Venango, | Mr. Porter Phipps, Kennerdell. |
| Warren, | Mr. R. J. Weld, Sugar Grove. |
| | Mr. J. P. Samuelson, Chandler's Valley. |
| Washington, | Mr. J. G. Berry, Primrose. |
| | Mr. J. B. Painter, Independence. |
| Wayne, | Mr. W. E. Perham, Niagara. |
| Westmoreland, | Mr. Geo. S. Barnhart, Greensburg. |
| | Mr. Daniel H. Pershing, Stauffer. |
| | Mr. John W. Welch, Bradenville. |
| Wyoming, | Mr. E. H. Pinder, Centremoreland. |
| | Mr. C. E. Henning, North Mehoopany. |
| York, | Mr. George F. Saubel, Brodbecks. |
| | Hon. James A. Stahle, Emigsville, |

## II.—ADDRESSES OF LIME BURNERS AND DEALERS GIVING INFORMATION.

| | |
|---|---|
| Berks, | Mr. M. G. Oberholtzer, Bechtelsville. |
| | J. S. Pearson & Co., Calcium. |
| | Dr. D. Heber Plank, Morgantown. |
| | Mr. Jacob Shaffner, Host. |
| Blair, | Keystone Lime and Stone Company, Tyrone. |
| | Mr. John Manning, Hollidaysburg. |
| | Mr. J. King McLanahan, Jr., Hollidaysburg. |
| Chester, | Avondale Lime and Stone Co., Avondale. |
| | Mr. Isaac Lesher, Williamson. |
| Jefferson, | Mr. Joseph M. Swisher, Punxsutawney. |
| Lancaster, | Mr. I. Galen Lefevre, Quarryville. |
| Lebanon, | Mr. John A. Bachman, Annville. |
| Lehigh, | Mr. A. W. Held, Fogelsville. |
| | Mr. E. D. Boyer, Catasauqua. |
| Lycoming, | Mr. Abraham Meyer, Cogan House. |
| | Mr. J. Sebring, Jersey Shore. |
| Monroe, | Mr. John P. Carmer, Bossardsville. |
| | Mr. Peter M. Heller, Bossardsville. |
| | Mr. Allen Metzger, Stormville. |
| Montgomery, | Mr. G. W. H. Corson, Plymouth Meeting. |
| | Todd & Son, Port Kennedy. |
| Northampton, | Mr. Edward Fehnel, Nazareth. |
| Northumberland, | Mr. A. C. Baylor, Milton. |
| Tioga, | Mr. D. F. Gates, Mansfield. |
| York, | Bittinger & Eberly, Hanover. |
| Sussex, N. J., | Mr. George N. Cole, Montague. |

# APPENDIX B.

## ANALYSES OF PENNSYLVANIA LIMESTONES.

COMPILED BY WILLIAM FREAR AND C. A. BROWNE, JR., FROM THE REPORT OF THE SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA; THE CATALOGUE OF EXHIBITS OF THE DEPARTMENT OF MINES, WORLD'S FAIR COMMISSION OF THE STATE OF PENNSYLVANIA; AND THE RECORDS OF THE PENNSYLVANIA STATE COLLEGE AGRICULTURAL EXPERIMENT STATION.

### SYMBOLS USED.

**$Al_2 O_3$.—Alumina.**
**$Ca Co_3$.—Carbonate of lime.**
**Fe.—Iron.**
**$Fe O$.—Iron oxid.**
**$Fe_2 O_3$.—Iron peroxid.**
**$Fe_2 CO_3$.—Carbonate of iron.**
**$Fe S_2$.—Iron pyrites.**
**$H_2 O$.—Water.**
**$Mg CO_3$.—Carbonate of magnesia.**
**$Mn_2 O_3$.—Manganese oxid.**
**$Ca SO_4$.—Calcium sulfate.**
**$Si O_2$.—Silica.**
**$SO_3$.—Sulfuric acid.**
**$P_2 O_5$.—Phosphoric acid.**
**$Mn CO_3$.—Carbonate of manganese.**
**$K_2O$.—Potash.**

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
|---|---|---|---|---|---|
| 1. | Armstrong, | Putneyville, | Hamilton, | Freeport Upper limestone, | Dark gray, tough. |
| 2. | Armstrong, | Logansport, | Mehaffey & McGill, | Freeport Upper limestone, | Pearl gray, brittle. |
| 3. | Armstrong, | Logansport, | Mehaffey & McGill, | Freeport Upper limestone, | Pearl gray, tough. |
| 4. | Armstrong, | Logansport, | Mehaffey & McGill, | Freeport Upper limestone, | Light pearl gray, hard. |
| 5. | Armstrong, | Rural Village, | J. Riefer, | Freeport Upper limestone, | Dark gray, tough calcite. |
| 6. | Armstrong, | Dayton, | Marshall, | Freeport Upper limestone, | Dark gray, tough calcite. |
| 7. | Armstrong, | Slate Lick, | Monroe, | Freeport Upper limestone, | Dark gray, tough. |
| 8. | Armstrong, | Manorville, | Dull & Co., | Freeport Upper limestone, | Dark gray, compact. |
| 9. | Armstrong, | Manorville, | Dull & Co., | Freeport Upper limestone, | Dark gray, contains pyrite. |
| 10. | Armstrong, | Manorville, | Dull & Co., | Freeport Upper limestone, | Pearl gray, calcite. |
| 11. | Armstrong, | Cochran's Mills, | Davis, | Johnstown cement, | Bluish gray, tough. |
| 12. | Armstrong, | Putneyville, | Putney, | Johnstown cement, | Bluish gray, hard, tough. |
| 13. | Armstrong, | Madison township, | Stewardson Furnace, | Ferriferous limestone, | Pearl gray, contains fossil casts. |
| 14. | Armstrong, | Madison township, | Stewardson Furnace, | Ferriferous limestone, | Pearl gray, contains fossil casts. |
| 15. | Armstrong, | Mahoning Furnace, | Colwell, | Ferriferous limestone, | Bluish gray, contains fossil casts. |
| 16. | Armstrong, | Kittanning, | Reynolds, | Ferriferous limestone, | Pearl gray, fossiliferous, calcite. |
| 17. | Armstrong, | South Bend, | George, | Ferriferous limestone, | Dark gray, fossiliferous, calcite. |
| 18. | Armstrong, | Greendale, | Rhea, | Ferriferous limestone, | Bluish gray fossiliferous, brittle. |
| 19. | Armstrong, | Buffalo Mills, | Graff, | Ferriferous limestone, | Dark gray, brittle. |
| 20. | Armstrong, | Kittanning, | Pine Creek Furnace, | Ferriferous limestone, | Bluish gray, compact. |
| 21. | Blair, | Altoona, | Baker, | Lewistown limestone, Lower Helderburg Form. No. VI, | Light bluish gray, fossiliferous upper layer. |
| 22. | Blair, | Altoona, | Baker, | Lewistown limestone, Lower Helderburg Form. No. VI, | Dark gray middle layer, contains calcite. |
| 23. | Blair, | Altoona, | Baker, | Lewistown limestone, Lower Helderburg Form. No. VI, | Gray lower layer, contains calcite. |
| 24. | Blair, | Hollidaysburg, | Creswell, | Lewistown limestone, Lower Helderburg Form. No. VI, | Dark gray, hard, contains calcite. |
| 25. | Blair, | Hollidaysburg, | Manning & Lewis, | Lewistown limestone, Lower Helderburg Form. No. VI, | Pearl gray, compact, contains calcite |

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|---|---|---|---|---|---|
| 26. | Blair, | Hollidaysburg, | Loop, | Lewistown limestone, Lower Helderburg Form. No. VI, | Dark gray, hard, contains calcite |
| 27. | Blair, | Tyrone, | Keystone Lime and Stone Co., | | Average supplied to Cambria Iron Co. |
| 28. | Blair, | Martinsburg, | John Manning. | | |
| 29. | Blair, | Frankstown, | J. K. McLanahan, | Limestone formation, No. VI., | |
| 30. | Blair, | Frankstown, | J. K. McLanahan, | Limestone formation, No. VI., | |
| 31. | Blair, | Catharine township, | Mt. Etna Furnace, | Limestone Form. No. II, | Bluish gray, contains calcite. |
| 32. | Blair, | | Springfield Furnace, | Limestone Form. No. II, | Dark blue, contains calcite. |
| 33. | Blair, | | Rodman Furnace, | Limestone Form. No. II, | Bluish gray, contains calcite. |
| 34. | Blair, | | Rodman Furnace, | Limestone Form. No. II, | Bluish gray, contained calcite. |
| 35. | Blair, | Roaring Springs, | Rodman Furnace, | Limestone Form. No. II, | Pearl gray. |
| 36. | Blair, | Tyrone, | | Limestone Form. No. II, | Light bluish gray, hard. |
| 37. | Blair, | Tyrone, | | Limestone Form. No. II, | Dark gray, hard. |
| 38. | Blair, | Birmingham, | Borie, | Limestone Form. No. II, | Bluish gray, hard, compact. |
| 39. | Blair, | Birmingham, | Keystone Zinc Co., | Limestone Form. No. II, | Bluish gray, conglomerate-like. |
| 40. | Bradford, | Burlington, | W. B. Kline, | Limestone Form. No. VIII, | "Burlington limestone," small fossil shells. |
| 41. | Berks, | Morgantown, | D. H. Plank, | Next to gneiss or primitive. | |
| 42. | Berks, | Bechtelsville, | M. G. Oberholtzer. | | |
| 43. | Berks, | Robesonia, | S. R. Deppan, | | For lime. |
| 44. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 45. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 46. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 47. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 48. | Beaver, | Vanport township, | Severn, | Ferriferous limestone, | Reddish gray, brittle. |
| 49. | Beaver, | Vanport township, | Power, | Ferriferous limestone, | Reddish gray, brittle. |
| 50. | Beaver, | Vanport township, | Power, | Ferriferous limestone, | Reddish gray, brittle, contains calcite and pyrite. |
| 51. | Beaver, | Vanport township, | Tygart, | Ferriferous limestone, | Reddish gray, brittle. |
| 52. | Cumberland, | Pine Grove, | Pine Grove Furnace, | Siluro-Cambrian No. II, | Brownish gray, hard. |
| 53. | Cumberland, | Mt. Holly, | Craig Head, | Siluro-Cambrian No. II, | Dark bluish gray, hard. |
| 54. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark bluish gray, soft, top of bed CXV. |
| 55. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark bluish gray, soft, bottom of bed CXV. |
| 56. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, soft, compact, top of bed LXXXVI. |
| 57. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, soft, compact, bottom of bed LXXXVI. |
| 58. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, hard, compact, calcite, top of bed LXXXVII. |
| 59. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, hard, compact, calcite, bottom of bed LXXXVII. |
| 60. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Light gray, hard, compact, calcite, top of bed XCVIII. |
| 61. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Light gray, hard, compact, bottom of bed XCVIII. |
| 62. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 63. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 64. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 65. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 66. | Centre, | Boalsburg, | W. C. Myer. | | |

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
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| 67. | Centre, | Boalsburg, | W. C. Myer. | | |
| 68. | Centre, | Bellefonte, | F. S. Rhoads, | ............ | Surface inch. |
| 69. | Centre, | Snow Shoe Basin, | ............ | ............ | Dirty gray, siliceous. |
| 70. | Centre, | Snow Shoe Basin, | ............ | ............ | Very silicious. |
| 71. | Centre, | Bellefonte, | Shortlidge, | Siluro-Cambrian Form. No. II,.. | Hard compact, containg calcite, pearl gray. |
| 72. | Centre, | Bellefonte, | Shortlidge, | Siluro-Cambrian Form. No. II,.. | Hard compact, contains calcite, pearl gray. |
| 73. | Centre, | Bellefonte, | Shortlidge, | Siluro-Cambrian Form. No. II,.. | Hard compact, contains calcite, pearl gray. |
| 74. | Chester, | Avondale, | Avondale Lime and Stone Co., | ............ | |
| 75. | Chester, | Barker Station, | Acme Lime Co., | ............ | For building. |
| 76. | Chester, | Barker Station, | Acme Lime Co., | ............ | For building and fluxing. |
| 77. | Chester, | Avondale, | Avondale Marble Co., | ............ | Statuary marble. |
| 78. | Chester, | London Grove Twp., | Swayne, | Siluro-Cambrian Form. No. II,.. | Brownish grey, crumbling. |
| 79. | Clarion, | New Athens, Madison Twp., | ............ | Freeport Upper limestone, | Dark gray, calcite. |
| 80. | Clarion, | Perry township, | Reichert, | Freeport Upper limestone, | Dark gray, calcite. |
| 81. | Clarion, | Toby township, | ............ | Freeport Upper limestone, | Bluish gray, hard. |
| 82. | Clarion, | Porter township, | ............ | Ferriferous limestone, | Pearl gray, brittle. |
| 83. | Clarion, | Clarion township, | Hindman, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 84. | Clarion, | Piney township, | Sligo Furnace, | Ferriferous limestone, | Bluish gray, tough. |
| 85. | Clarion, | Perry township, | Barger, | Ferriferous limestone, | Bluish gray, calcite. |
| 86. | Cambria, | Johnstown, | A. J. Hawes, | Cement bed, | Hard, brittle, contains pyrites: |
| 87. | Clearfield, | Glenn Hope, | ............ | ............ | Bluish gray, hard. |
| 88. | Clinton, | Nippenose Valley, | J. Wilsham, | Siluro-Cambrian No. II, | So-called "plaster." |
| 89. | Crawford, | Harmonsburg, Summit township, | Whiting & Brown, | ............ | A raw marl, covers 80 acres; used for lime and agriculture. |
| 90. | Dauphin, | Harrisburg, | Rutherford, | Limestone Form No. II, | Dark bluish gray, East quarry. |
| 91. | Dauphin, | Harrisburg, | Rutherford, | Limestone Form No. II, | Dark bluish gray, West quarry. |
| 92. | Dauphin, | Harrisburg, | Couffer, | Limestone Form No. II. | |
| 93. | Dauphin, | Harrisburg, | Frantz, | Limestone Form No. II. | |
| 94. | Dauphin, | Harrisburg, | Crumbler, | Limestone Form No. II. | |
| 95. | Dauphin, | Harrisburg, | Strickler, | Limestone Form No. II. | |
| 96. | Elk, | Brandy Camp, Horton twp., | J. S. Hyde, | Freeport Upper limestone, | Bluish gray, brittle. |

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| 97. | Elk, | Brandy Camp, Horton twp., | J. S. Chamberlain, | Freeport Lower limestone, | Bluish gray, brittle. |
| 98. | Elk, | Brandy Camp, Horton twp., | J. C. McAllister, | Freeport Lower limestone, | Pearl gray, brittle. |
| 99. | Elk, | Mead Run, Horton twp., | T. Fox, | Freeport Lower limestone, | Bluish gray, brittle. |
| 100. | Elk, | Benezette, | G. W. Winslow, | Ferriferous limestone, | Pearl gray, brittle, calcite. |
| 101. | Elk, | Fox township, | J. S. Chamberlain, | Ferriferous limestone, | Bluish gray, brittle. |
| 102. | Elk, | Brandy Camp, | J. C. McAllister, | Ferriferous limestone, | Bluish gray, brittle. |
| 103. | Elk, | Brandy Camp, | J. C. McAllister, | Johnstown cement bed, | Bluish gray, hard and tough. |
| 104. | Elk, | Brockport, | Oyster, | Ferriferous limestone, | Bluish black, shaly, fossiliferous, soft. |
| 105. | Elk, | Brockport, | Oyster, | Ferriferous limestone, | Dark blue, brittle. |
| 106. | Elk, | Brockport, | Oyster, | Ferriferous limestone, | Bluish black, shaly, fossiliferous. |
| 107. | Elk, | Jones township, | Gen. Kane, | Ferriferous limestone, | Reddish gray, brittle. |
| 108. | Elk, | Jones township, | Gen. Kane, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 109. | Elk, | Fox township, | | Clermont limestone, | Bluish gray, brittle. |
| 110. | Elk, | Benezette, | | Benezette Upper limestone, | Bluish gray, sandy fossiliferous. |
| 111. | Elk, | Benezette, | | Benezette Middle limestone, | Bluish gray, shaly, fossiliferous. |
| 112. | Elk, | Caledonia, | | | Bluish gray, crystalline, has pyrites. |
| 113. | Elk, | Caledonia, | | | Bluish gray, very sandy. |
| 114. | Elk, | St. Mary's, | J. M. Wittman. | | |
| 115. | Fayette, | Georges township, | Oliphant Furnace, Oliphant, | Sewickley limestone, | Blue, compact and contains pyrites. |
| 116. | Fayette, | Uniontown, | Lemont Furnace, | Redstone limestone, | Compact, brittle, contains calcite. |
| 117. | Fayette, | Uniontown, | Lemont Furnace, | Pittsburgh limestone, | Bluish gray, soft, brittle. |
| 118. | Forest, | Tionesta, | Kelly, | Tionesta limestone, | Bluish gray, hard, tough, sandy. |
| 119. | Franklin, | Mont Alto, | Mine No. 3 Iron Co., | | Yellowish brown, soft. |
| 120. | Franklin, | Mont Alto, | Mine No. 4 Iron Co., | | Light bluish gray, soft. |
| 121. | Franklin, | Mont Alto, | Shiery, | | A true lithological dolomite. |
| 122. | Franklin, | Williamson, | Hawbecker, | | Best quality from quarry. |
| 123. | Franklin, | Williamson, | Hawbecker, | | Worst quality from quarry. |
| 124. | Franklin, | Scotland, | Battin, | Siluro-Cambrian No. II, | A cement quarry, now abandoned. |
| 125. | Huntingdon, | Union Furnace Station, | H. J. McAteer, | | For fluxing and R. R. ballast. |
| 126. | Huntingdon, | Three Springs, | Hudson, | Lewistown limestone, Lower Helderberg Form. No. VI, | Compact, bluish gray, 70 feet above bottom of formation. |
| 127. | Huntingdon, | Three Springs, | Hudson, | Lewistown limestone, Lower Helderberg Form. No. VI, | Compact bluish gray, 60 feet above bottom of formation. |
| 128. | Huntingdon, | Three Springs, | Hudson, | Lewistown limestone, Lower Helderberg Form. No. VI, | Compact bluish gray, 50 feet above bottom of formation. |
| 129. | Huntingdon, | Saltillo, | C. R. McCarthy, | Lewistown limestone, Lower Helderberg Form. No. VI, | Crystalline bluish gray, contains calcite. |
| 130. | Huntingdon, | Saltillo, | C. R. McCarthy, | Lewistown limestone, Lower Helderberg Form. No. VI, | Siliceous, bluish gray. |
| 131. | Huntingdon, | Saltillo, | | Lewistown limestone, Lower Helderberg Form. No. VI, | Water line cement beds, 375 feet above bottom of formation. |

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
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| 132. | Huntingdon, | Saltillo, | | Lewistown limestone, Lower Helderberg Form. No. VI, | Water line cement beds, 190 feet above bottom of formation. |
| 133. | Huntingdon, | Saltillo, | | Lewistown limestone, Lower Helderberg Form. No. VI, | Water line cement beds, 160 feet above bottom of formation. |
| 134. | Huntingdon, | McAlevy's Fort, | Barr, | 80+ ft. below fossil ore, | Bluish gray, dark, compact, contains calcite. |
| 135. | Huntingdon, | Robertsdale, | | | Conglomerate of limestone and red shale. |
| 136. | Huntingdon, | Broad Top City, | J. Diggins, | | Conglomerate of limestone and red shale. |
| 137. | Huntingdon, | Todd township, | John Whitney, | Red Shale No. XI, Mauch Chunk, | Bluish gray, tough. |
| 138. | Indiana, | West Lebanon, | A. H. Fulton, | Pittsburgh limestone, | Bluish gray, compact, brittle. |
| 139. | Indiana, | Five Points, | Rev. S. Brown, | Freeport Upper limestone, | Bluish gray, compact, calcite. |
| 140. | Indiana, | Chambersville, | Groft Brothers, | Freeport Upper limestone, | Dark bluish gray, compact. |
| 141. | Indiana, | Jacksonville, | S. C. Hazlelett, | Freeport Upper limestone, | Bluish gray, compact. |
| 142. | Indiana, | Homer, | D. R. Griffith, | Freeport Upper limestone, | Bluish gray, compact. |
| 143. | Indiana, | Blairsville, | G. Livengood, | Freeport Upper limestone, | Bluish gray, compact, calcite. |
| 144. | Indiana, | Richmond, | Isaac Simpson, | Ferriferous limestone, | Bluish gray, hard, fossiliferous. |
| 145. | Indiana, | Blairsville, | Doty, | 120 ft. below Pittsburgh coal bed, | Bluish gray, compact, contains calcite. |
| 146. | Indiana, | Decher's Point, | S. Palmer, | Freeport Lower limestone, | Bluish gray, brittle. |
| 147. | Indiana, | Blairsville, | P. Brown, | Freeport Lower limestone, | Bluish gray, brittle. |
| 148. | Indiana, | Smithport, | A. Gorman, | Johnstown cement bed, | Upper part of deposit, hard. |
| 149. | Indiana, | Smithport, | A. Gorman, | Johnstown cement bed, | Lower part of deposit, hard. |
| 150. | Indiana, | Black Lick Station, | Tyhawk, | Johnstown cement bed, | Bluish gray, compact. |
| 151. | Indiana, | Smith's Station, Blairsville, | Robert Smith, | Sewickly limestone, | Compact, contains calcite. |
| 152. | Indiana, | Marion Center, | I. H. Rochester, | | Compact gray, red tinge, coarse top seam. |
| 153. | Indiana, | Marion Center, | J. H. Rochester, | | Red, middle seam. |
| 154. | Indiana, | Marion Center, | I. H. Rochester, | | Red, bottom seam. |
| 155. | Indiana, | Home, | T. St. Clair Thompson, | | Surface rock. |
| 156. | Indiana, | Home, | T. St. Clair Thompson. | | |
| 157. | Indiana, | Home, | T. St. Clair Thompson. | | |

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| 158. | Juniata, | Mexico, | Mr. Rodgers | | |
| 159. | Jefferson, | Big Run, | Jas. Smith, | Lower Barren Measures, | Bluish gray, brittle. |
| 160. | Jefferson, | Big Run, | James Smith, | Lower Barren Measures, | Pearl gray, hard and tough. |
| 161. | Jefferson, | Big Run, | Jacob Smith, | Lower Barren Measures, | Bluish gray, brittle, calcite. |
| 162. | Jefferson, | Brockwayville, | N. B. Lane, | Freeport Upper limestone, | Pearl gray, brittle, calcite. |
| 163. | Jefferson, | Perrysville, | John Iler, | Freeport Upper limestone, | Pearl gray, sandy. |
| 164. | Jefferson, | Perrysville, | John Iler, | Freeport Upper limestone, | Bluish gray, brittle, calcite. |
| 165. | Jefferson, | Frostburg, | D. Hopkins, | Freeport Upper limestone, | Pearl gray, brittle, calcite. |
| 166. | Jefferson, | Worthville, | A. Hoffman, | Freeport Upper limestone, | Pearl gray, brittle, calcite. |
| 167. | Jefferson, | Brockwayville, | N. B. Lane, | Freeport Lower limestone, | Brownish gray, brittle. |
| 168. | Jefferson, | Corsica, | ........ | Freeport Lower limestone, | Brownish gray, brittle. |
| 169. | Jefferson, | Brockwayville, | N. B. Lane, | Johnston's cement bed, | Dark gray, hard, tough. |
| 170. | Jefferson, | Perrysville, | John Iler, | Johnston's cement bed, | Dark gray, hard, tough. |
| 171. | Jefferson, | Brockwayville, | C. Bovaird, | Ferriferous limestone, | Pearl gray, brittle. |
| 172. | Jefferson, | Sprankle Mills, | W. Hanna, | Ferriferous limestone, | Bluish gray, hard, fossil casts. |
| 173. | Jefferson, | Worthville, | A. Enty, | Ferriferous limestone, | Bluish gray, brittle, fossiliferous. |
| 174. | Jefferson, | Dowlingville, | S. Shields, | Ferriferous limestone, | Pearl gray, calcite, fossiliferous. |
| 175. | Jefferson, | Brookville, | ........ | ........ | Bluish gray, hard, tough, sandy. |
| 176. | Lancaster, | Lancaster, | McHoain & Brother, | ........ | Quarry worked 50 yrs., 10,000 cu. yds. per year. |
| 177. | Lancaster, | Columbia, | Chestnut Hill Iron Ore Co., | | |
| 178. | Lancaster, | Pequa Valley, | S. D. McHoain, | ........ | For building and land. |
| 179. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Light bluish gray, hard and brittle, South quarry. |
| 180. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Light brownish gray, hard and brittle, North quarry. |
| 181. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Dark bluish gray, hard and tough, North quarry. |
| 182. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Brownish gray, crumbling, North quarry. |
| 183. | Lawrence, | Wampum, | J. K. Shinn & Bro., | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 184. | Lawrence, | Mt. Jackson, | McCord, | Ferriferous limestone, | Pearl gray, brittle, calcite. |
| 185. | Lawrence, | New Castle, | Green Marquis & Johnson, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 186. | Lawrence, | Croton, | Moffit, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 187. | Lebanon, | Annville, | J. A. Bachman, | ........ | Used for glass mfg. |
| 188. | Lebanon, | Heilmandale, | Mr. Heilman. | | |
| 189. | Lehigh, | Catasauqua, | Ed. Boyer. | | |
| 190. | Lehigh, | White Hall Station, | Mary Kohler, | Siluro-Cambrian limestone Form. No. II, | Brecciated limestone, blue and gray. |
| 191. | Lehigh, | Allentown, | Ephraim Wenner, | Siluro-Cambrian limestone Form. No. II, | Hard limestone, bluish gray, pyrites. |
| 192. | Lehigh, | Allentown, | Ephraim Wenner, | Siluro-Cambrian limestone Form. No. II, | Soft limestone, dark blue, laminated. |
| 193. | Lehigh, | Catasauqua, | Ed. Guth, | Siluro-Cambrian limestone Form. No. II, | Slatey, dark blue. |
| 194. | Lehigh, | Guth's Station, | Thomas Iron Co., | Siluro-Cambrian limestone Form. No. II, | Some quartz, bluish gray. |

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
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| 195. | Lehigh, | Ironton, | Ironton R. R. Co., | Siluro-Cambrian limestone Form. No. II, | Hard, compact, bluish gray. |
| 196. | Lehigh, | Alburtis, | Thomas Iron Co., | ........ | Bluish gray. |
| 197. | Lehigh, | Alburtis, | Thomas Iron Co., | ........ | Bluish gray, crystalline. |
| 198. | Lehigh, | Trexlertown, | Mrs. Kuhn, | ........ | Bluish gray, siliceous. |
| 199. | Lehigh, | Trexlertown, | Franz, | ........ | Dark blue, siliceous. |
| 200. | Lehigh, | Allentown, | ........ | ........ | Disintegrated. |
| 201. | Lehigh, | Allentown, | ........ | ........ | Fresh, 1½ in. under No. 200. |
| 202. | Lehigh, | Alburtis, | Ruths, Thos. Iron Co. | | |
| 203. | Lycoming, | Jersey Shore, Porter township, | Wilson, | Lewistown limestone No. VI, | Bluish gray, soft. |
| 204. | Lycoming, | Jersey Shore, Porter township, | Ferguson, | Lewistown limestone No. VI, | Bluish gray, hard, compact, calcite. |
| 205. | Lycoming, | Jersey Shore, Porter township, | Bailey, | Lewistown limestone No. VI, | Bluish gray, hard. |
| 206. | Mifflin, | Belleville, | D. Campbell, | Siluro-Cambrian limestone Form. No. II, | Fossiliferous, contains calcite. |
| 207. | Mifflin, | Belleville, | A. Campbell, | Siluro-Cambrian limestone Form. No. II, | Probably top of Calciferous, black and gray. |
| 208. | Mifflin, | Belleville, | A. Campbell, | Siluro-Cambrian limestone Form. No. II, | Bottom of Chazy, hard, light bluish gray. |
| 209. | Mifflin, | Belleville, | Greenwood Ore Bank, | Siluro-Cambrian limestone Form. No. II, | Magnesian limestone, contains calcite. |
| 210. | Monroe, | Bossardsville, | P. M. Hiller. | | |
| 211. | Montgomery, | Port Kennedy, | Todd & Son, | Dolomite stratum. | |
| 212. | Montgomery, | Whitemarsh township, | G. W. H. Corson, | ........ | For building and lime. |
| 213. | Montgomery, | King of Prussia, | Schwayer & Liess, | ........ | Carbonaceous matter 0.13. |
| 214. | Perry, | Newport, | ........ | Chemung limestone, | Comminuted shells, siliceous matrix, reddish. |
| 215. | Perry, | Newport, | ........ | Chemung limestone, | Comminuted shells, siliceous matrix, reddish. |
| 216. | Perry, | Newport, | ........ | Chemung limestone, | Comminuted shells, siliceous matrix, reddish. |

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| 217. | Perry, | Mahonoy Valley, | Still, | Lewistown limestone, | Dark blue, brittle, slatey. |
| 218. | Perry, | Mahonoy Valley, | Still, | Lewistown limestone, | Bluish gray, brittle, fossiliferous, calcite. |
| 219. | Somerset, | Somerset, | Zimmerman, | Johnstown cement bed, | Bluish gray, compact, sandy. |
| 220. | Somerset, | Friedensburg, | Reitz, | Johnstown cement bed, | Bluish gray, compact, hard. |
| 221. | Somerset, | Stoystown, | Wilt, | Johnstown cement bed, | Bluish gray, compact. |
| 222. | Somerset, | Sipesville, | J. J. Pile, | Johnstown cement bed, | Bluish gray, compact, brittle. |
| 223. | Somerset, | Jenner Cross Roads, | J. W. Beam, | Johnstown cement bed, | Compact, upper bench of quarry. |
| 224. | Somerset, | Jenner Cross Roads, | J. W. Beam, | Johnstown cement bed, | Compact, middle bench of quarry. |
| 225. | Somerset, | Jenner Cross Roads, | J. W. Beam, | Johnstown cement bed, | Compact, lower bench of quarry. |
| 226. | Somerset, | Shade township, | Rodgers, | Johnstown cement bed, | Bluish gray, hard, sandy. |
| 227. | Somerset, | Davidsville, | Trevorrow, | Johnstown cement bed, | Bluish gray, brittle. |
| 228. | Somerset, | Scalp Level, | Weaver, | Johnstown cement bed, | Bluish gray, compact. |
| 229. | Somerset, | Salisbury, | S. S. Flickenger, | Little Pittsburgh limestone, | Slatey, contains coal, much pyrite. |
| 230. | Somerset, | Ursina, | Pittsburgh Coal, Coke & Iron Co., | Elk Lick limestone, | Bluish gray, compact. |
| 231. | Somerset, | Meyersdale, | Elias Yoder, | Elk Lick limestone, | Bluish gray, compact. |
| 232. | Somerset, | Jenner Cross Roads, | Peter Berkey, | Elk Lick limestone, | Bluish gray, compact. |
| 233. | Somerset, | Salisbury, | M. J. Beechy, | Redstone limestone, | Pearl gray, crystalline. |
| 234. | Somerset, | Buckstown, | Burkit, | | Concretionary nodules of greenish limestone. |
| 235. | Somerset, | Forwardstown, | Harshberger, | | Bluish black, compact, contains pyrites. |
| 236. | Somerset, | Meyersdale, | Keystone Coal and Mfg. Co., | Great limestone, | Bluish gray, hard compact, Fe as carbonate. |
| 237. | Somerset, | Meyersdale, | Saylor Hill, | Great limestone, | Bluish gray, brittle, compact, Fe as carbonate. |
| 238. | Somerset, | Meyersdale, | Saylor Hill, | Sewickly limestone, | Yellowish gray, brittle, compact, Fe as carbonate. |
| 239. | Somerset, | Salisbury, | J. M. Hayes, | Sewickly limestone, | Bluish gray, brittle, hard, Fe as carbonate. |
| 240. | Sullivan, | Millview, | Lucke, | Chemung Formation limestone No. VIII, | Fossiliferous, contains calcite, rose tinted, upper bench. |
| 241. | Sullivan, | Millview, | Lucke, | Chemung Formation limestone No. VIII, | Fossiliferous, contains calcite, rose tinted, lower bench. |
| 242. | Tioga, | Mansfield, | G. R. Wilson, | Chemung Formation limestone No. VIII, | Contains comminuted sea shells and shale. |
| 243. | Washington, | Canonsburg, | | Great lower limestone division, | Fe reckoned as carbonate. |
| 244. | Washington, | Canonsburg, | | Great lower limestone division, | Fe reckoned as carbonate. |
| 245. | Washington, | Canonsburg, | | Great lower limestone division, | Fe reckoned as carbonate. |
| 246. | Washington, | Somerset, | | Great lower limestone division, | Fe reckoned as carbonate. |
| 247. | Washington, | Washington, | | Upper Washington limestone, | Fe reckoned as carbonate. |
| 248. | Wayne, | Cherry Ridge township, | | Catskill limestone, | Reddish gray, brecciated. |
| 249. | Wayne, | Cherry Ridge township, | | Catskill limestone, | Greenish gray, brecciated, contains malachite. |
| 250. | Wayne, | Oregon township, | | Catskill limestone, | Greenish gray, siliceous. |
| 251. | Wayne, | Oregon township, | | Catskill limestone, | Greenish gray, sandy. |
| 252. | Westmoreland, | Kelley's Station, | Wining & Cuisan, | Upper limestone, | Pearl gray, compact, brittle, calcite. |
| 253. | Westmoreland, | Salina, | Kier Bros., | Upper limestone, | Reddish gray, brittle. |

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
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| 254. | Westmoreland, | Mt. Pleasant, | Freeman, | | So-called "Black ore," sandy looking. |
| 255. | York, | Wrightsville, | Kerr Bros., | | For lime and fluxes. |
| 256. | York, | Dillsburg, | | | Greenish gray. |
| 257. | York, | Xenia P. O., | | | Greenish gray, contains manganese. |
| 258. | York, | | | | Conglomerate limestone. |
| 259. | York, | Seitzland, | | | White crystalline limestone. |
| 260. | York, | Wrightsville. | | | |
| 261. | York, | Mengis Mill Station, | Sprenkel, | Siluro-Cambrian limestone Form. No. II, | Greenish gray, and pink, compact and laminated. |
| 262. | York, | Mengis Mill Station, | Sprenkel, | Siluro-Cambrian limestone Form. No. II, | Bluish gray, contains magnetic oxid of Fe. |
| 263. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 264. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 265. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 266. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 267. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 268. | York, | Hanover, | Bittinger & Eberley. | | |
| 269. | York, | Wrightsville, | C. Kerr. | | |
| 270. | York, | Wrightsville, | C. Kerr. | | |
| 271. | York, | Wrightsville, | C. Kerr. | | |
| 272. | York, | Wrightsville, | C. Kerr. | | |
| 273. | York, | Wrightsville, | C. Kerr. | | |

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
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| | | | Page. | | | | | | | | |
| 1. | ........ | 291 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 9,520 | 2,568 | 84.557 | 1.868 | ........ | 0.055* | ........ | 1.132 |
| 2. | ........ | 292 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 0.830 | 0.964 | 96.453 | 1.445 | ........ | 0.016* | ........ | 0.392 |
| 3. | ........ | 293 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.200 | 1.340 | 93.214 | 2.065 | ........ | 0.009* | ........ | 1.172 |
| 4. | ........ | 294 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 3.170 | 1.207 | 93.571 | 1.324 | ........ | 0.067* | ........ | 0.661 |
| 5. | ........ | 295 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 5.030 | 2.557 | 88.839 | 1.513 | ........ | 0.048* | ........ | 2.013 |
| 6. | ........ | 296 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 1.920 | 1.246 | 94.928 | 1.210 | ........ | 0.041* | ........ | 0.655 |
| 7. | ........ | 297 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 1.850 | 1.182 | 94.642 | 1.574 | ........ | 0.028* | ........ | 0.724 |
| 8. | ........ | 298 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 4.830 | 2.002 | 89.303 | 1.900 | ........ | 0.048* | ........ | 1.917 |
| 9. | ........ | 299 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 7.310 | 3.367 | 82.589 | 5.751 | ........ | 0.144* | ........ | 0.839 |
| 10. | ........ | 300 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 4.520 | 1.860 | 89.857 | 2.898 | ........ | 0.139* | ........ | 0.826 |
| 11. | ........ | 301 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 23.840 | 7.730 | 53.750 | 9.989 | ........ | 0.300* | ........ | 4.391 |
| 12. | ........ | 302 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 22.280 | 7.450 | 64.160 | 1.838 | ........ | 0.698* | ........ | 3.574 |
| 13. | ........ | 303 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.030 | 1.288 | 95.535 | 0.907 | 0.064 | 0.082 | $Mn_2O_3$.206, $H_2O$,.150 | ........ |
| 14. | ........ | 304 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 0.790 | 1.462 | 96.007 | 1.498 | ........ | 0.078* | ........ | 0.165 |
| 15. | ........ | 305 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.300 | 1.383 | 94.721 | 1.044 | ........ | 0.108* | ........ | 0.444 |
| 16. | ........ | 306 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.110 | 0.930 | 95.567 | 1.422 | ........ | 0.080* | ........ | ........ |
| 17. | ........ | 307 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.100 | 2.089 | 94.185 | 1.483 | ........ | 0.071* | ........ | 0.072 |
| 18. | ........ | 308 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 3.420 | 1.667 | 93.246 | 1.740 | ........ | 0.074* | ........ | ........ |
| 19. | ........ | 309 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 3.220 | 1.713 | 93.292 | 0.968 | ........ | 0.108* | ........ | 0.699 |
| 20. | ........ | 947 | 298 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 0.870 | 1.000 | 96.785 | 1.278 | 0.150* | 0.066* | ........ | 0.351 |
| 21. | ........ | 802a | 301 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 2.500 | 0.842 | 95.664 | 1.547 | 0.256* | 0.034* | ........ | ........ |
| 22. | ........ | 802b | 301 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 3.000 | 0.644 | 95.089 | 1.581 | 0.073* | 0.046* | ........ | ........ |
| 23. | ........ | 802c | 301 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 3,020 | 0.570 | 95.571 | 1.521 | 0.068* | 0.021* | ........ | ........ |
| 24. | ........ | 648 | 302 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 1.800 | †0.054 | 95.251 | 2,265 | 0.133* | 0.007* | $FeCO_3$ 0.745, ........ | ........ |
| 25. | ........ | 649 | 302 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 1.615 | †0.035 | 96.164 | 1.589 | 0.175* | 0.011* | $FeCO_3$ 0.615, ........ | ........ |
| 26. | ........ | 650 | 302 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 10.850 | †0.043 | 84.782 | 3.859 | 0.133* | 0.009* | $FeCO_3$ 0.534, ........ | ........ |
| 27. | ........ | ........ | ........ | 2.000 | ........ | 96.000 | 2.000 | ........ | trace | ........ | ........ |
| 28. | ........ | ........ | ........ | ........ | ........ | 98.000 | ........ | ........ | ........ | ........ | 2.00 |
| 29. | ........ | ........ | ........ | 1.400 | 1.600 | 94.480 | 2.570 | ........ | trace | ........ | ........ |
| 30. | ........ | ........ | ........ | 1.600 | 2.600 | 92.900 | 2.880 | ........ | trace | ........ | ........ |
| 31. | S. S. Hartranft...... | 786 | 306 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 0.910 | 0.264 | 94.930 | 3.866 | 0.133* | 0.026* | ........ | ........ |
| 32. | ........ | 807 | 306 $M_3$ 1876-8, 2d Geol. Surv. Pa.,... | 3.210 | 1.126 | 78.196 | 17.510 | 0.213* | 0.084* | ........ | ........ |
| 33. | ........ | 964a | 306 $M_3$ 1876-8, 2d Geol. Surv. Pa ,... | 8.570 | 1.850 | 78.176 | 10.746 | 0.373* | 0.066* | ........ | 0.219 |

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*Recalculated. †$Al_2O_3$ only.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $M_gCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Page. | | | | | | | | |
| 34. | .......................... | 964b | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 4.380 | 0.640 | 91.892 | 2.875 | 0.243* | 0.050* | .......................... | ....... |
| 35. | .......................... | 964c | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 1.330 | 0.234 | 64.571 | 44.180 | 0.005* | 0.007* | .......................... | ....... |
| 36. | .......................... | 1,011a | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 5.880 | 1.682 | 90.389 | 2.245 | .......... | .......... | Fe as carbonate,... | ....... |
| 37. | .......................... | 1,011b | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 3.620 | 0.189 | 92.115 | 4.234 | .......... | .......... | Fe as carbonate,... | ....... |
| 38. | .......................... | 85 | 307 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 10.380 | 2.850 | 48.030 | 37.670 | 1.158* | 0.096* | .......................... | ....... |
| 39. | .......................... | 86 | 307 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 29.100 | 1.190 | 53.870 | 41.320 | 0.113* | 0.030* | .......................... | 0.567 |
| 40. | .......................... | 334 | 299 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 18.010 | 7.041 | 73.250* | 2.329* | 0.167 | 0.279 | .......................... | ....... |
| 41. | Brook Iron Co., ...... | ....... | .......................................... | .............. | .............. | .............. | .......... | .......... | .......... | .......................... | ....... |
| 42. | W. C. Henderson,.... | ....... | .......................................... | 0.850 | 0.900 | 54.240 | 43.960 | .......... | .......... | .......................... | ....... |
| 43. | .......................... | ....... | 80 Catalogue of Exhibits, ........... | .............. | 1.400 | 94.440 | .......... | .......... | .......... | .......................... | 0.300 |
| 44. | Clement G. Smith, .. | ....... | .......................................... | 2.10 | †0.510 | 73.730 | 20.100* | .......... | .......... | $SiO_2$, 1.67, ........ | 1.890 |
| 45. | .......................... | ....... | .......................................... | 2.770 | †1.520 | 63.530 | 30.200* | .......... | .......... | $SiO_2$, 2.26, ........ | ....... |
| 46. | .......................... | ....... | .......................................... | trace | trace | 94.500 | trace | .......... | .......... | $SiO_2$, trace, ....... | 5.500 |
| 47. | .......................... | ....... | .......................................... | 3.800 | 0.900 | 75.500 | 19.500 | .......... | trace | .......................... | 2.780 |
| 48. | .......................... | 596 | 297 MM 1876-8, 2d Geol. Surv. Pa.,.. | 2.770 | 1.823 | 93.482 | 1.544 | 0.075* | 0.108* | .......................... | 0.198 |
| 49. | .......................... | 599 | 297 MM 1876-8, 2d Geol. Surv. Pa.,.. | 7.030 | 2.324 | 88.464 | 1.445 | 0.243* | 0.066* | .......................... | 0.428 |
| 50. | .......................... | 600 | 297 MM 1876-8, 2d Geol. Surv. Pa.,.. | 4.780 | 1.291 | 91.607 | 1.566 | 0.725* | 0.069* | .......................... | ....... |
| 51. | .......................... | 555 | 297 MM 1876-8, 2d Geol. Surv. Pa.,.. | 4.800 | 1.589 | 91.089 | 1.587 | 0.118* | 0.092* | .......................... | 0.525 |
| 52. | .......................... | 278 | 80 $M_2$ 1879-80, 2d Geol. Surv. Pa.,.. | 2.310 | 4.503 | 72.321 | 20.591 | 0.028* | 0.108* | $Mn_2O_3$ .433, .......* | ....... |
| 53. | .......................... | 279 | 80 $M_2$ 1879-80, 2d Geol. Surv. Pa.,.. | 8.410 | 0.571 | 86.357 | 5.236 | 0.035* | 0.030* | .......................... | ....... |
| 54. | Walton Quarries,.... | ....... | 340 MM 1876-8, 2d Geol. Surv. Pa.,.. | 1.870 | 0.300 | 97.732 | 0.908 | .......... | .......... | .......................... | ....... |
| 55. | Walton Quarries,.... | ....... | 341 MM 1876-8, 2d Geol. Surv. Pa.,.. | 1.670 | 0.900 | 95.121 | 1.952 | .......... | .......... | .......................... | 0.357 |
| 56. | Walton Quarries,.... | ....... | 334 MM 1876-7, 2d Geol. Surv. Pa.,.. | 0.620 | 0.390 | 98.912 | 1.134 | .......... | .......... | .......................... | ....... |
| 57. | Walton Quarries,.... | ....... | 335 MM 1876-8, 2d Geol. Surv. Pa., .. | 3.820 | 0.580 | 95.372 | 1.339 | .......... | .......... | .......................... | ....... |
| 58. | Walton Quarries,.... | ....... | 334 MM 1876-8, 2d Geol. Surv. Pa.,.. | 15.870 | 3.020 | 54.134 | 28.123 | .......... | .......... | .......................... | ....... |
| 59. | Walton Quarries,.... | ....... | 335 MM 1876-8, 2d Geol. Surv. Pa.,.. | 12.500 | 2.630 | 52.025 | 33.657 | .......... | .......... | .......................... | ....... |
| 60. | Walton Quarries,.... | ....... | 336 MM 1876-8, 2d Geol. Surv. Pa.,.. | 6.660 | 0.800 | 60.018 | 32.828 | .......... | .......... | .......................... | ....... |
| 61. | Walton Quarries,.... | ....... | 337 MM 1876-8, 2d Geol. Surv. Pa.,.. | 7.790 | 1.090 | 62.086 | 29.423 | .......... | .......... | .......................... | ....... |
| 62. | J. A. Fries, ........ | 10,640 | Pa. Expt. Station records, .......... | 6.510 | .............. | 87.590 | 2.520 | .......... | .......... | .......................... | 8.710 |
| 63. | J. A. Fries, ....... | 10,641 | Pa. Expt. Station records, .......... | 5.960 | .............. | 91.210 | 2.210 | .......... | .......... | .......................... | 4.260 |
| 64. | J. A. Fries, ....... | 10,642 | Pa. Expt. Station records, .......... | 16.070 | .............. | 66.960 | 2.230 | .......... | .......... | .......................... | 14.740 |
| 65. | J. A. Fries, ....... | 10,643 | Pa. Expt. Station records, .......... | 5.890 | .............. | 87.730 | 1.620 | .......... | .......... | .......................... | 0.620 |
| 66. | W. S. Sweetser, ... | 26,169 | Pa. Expt. Station records, .......... | 6.640 | .............. | 84.830 | .......... | .......... | .......... | .......................... | 3.380 |

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†$Al_2O_3$ only.

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 67. | W. S. Sweetser, | 24,170 | Pa. Expt. Station records, | 11.680 | ... | 75.080 | ... | ... | ... | ... | 13.290 |
| 68. | C. P. Beistle, | 30,108 | Pa. Expt. Station records, | 1.430 | ... | 97.590 | ... | ... | 0.040 | ... | 0.950 |
| 69. | A. S. McCreath, | ... | 76 M 1874, 2d Geol. Surv. Pa., | 18.730 | ... | 42.941 | 22.764 | 1.500* | 0.114* | ... | 12.951 |
| 70. | A. S. McCreath, | ... | 76 M Pa., 1874, 2d Geol. Survey Pa., | 23.530 | ... | 51.153 | 13.265 | trace | 0.657* | ... | 11.495 |
| 71. | J. Hartshorne, | 1,012a | 307 MM 2d G. S., 1876-8, | 0.540 | 0.203 | 97.890 | 1.285 | ... | ... | ... | 0.082 |
| 72. | J. Hartshorne, | 1,012b | 307 MM 2d G. S., 1876-8, | 0.190 | 0.320 | 98.322 | 1.170 | ... | ... | ... | ... |
| 73. | J. Hartshorne, | 1,012c | 307 MM 2d G. S., 1876-8, | 0.815 | 0.377 | 97.532 | 1.210 | ... | ... | ... | 0.066 |
| 74. | ... | ... | ... | 5.000* | ... | 75.000* | 20.000 | ... | ... | ... | ... |
| 75. | ... | ... | 79 Catalogue of Exhibits, | 36.270 | 1.910 | 58.520 | 3.870 | ... | ... | Soluble $SiO_2$, 0.07, | ... |
| 76. | ... | ... | 79 Catalogue of Exhibits, | 4.650 | 0.390 | 83.390 | 12.420 | ... | ... | Soluble $SiO_2$, 0.04, | ... |
| 77. | ... | ... | 81 Catalogue of Exhibits, | 1.610 | ... | 58.010 | 40.380 | ... | ... | ... | ... |
| 78. | ... | 272 | 79 $M_3$ 2d G. S., 1879-80, | 1.950 | 0.613 | 54.071 | 43.309 | 0.033* | 0.007* | ... | 0.017 |
| 79. | ... | 310 | 86 $M_3$ 2d G. S., 1879-80, | 1.800 | 0.765 | 93.803 | 2.270 | ... | 0.018* | ... | 1.344 |
| 80. | ... | 311 | 86 $M_3$ 2d G. S., 1879-80, | 5.320 | 1.365 | 82.678 | 8.248 | ... | 0.051* | ... | 2.338 |
| 81. | ... | 312 | 86 $M_3$ 2d G. S., 1879-80, | 7.940 | 2.736 | 82.000 | 6.311 | ... | 0.034* | ... | 0.979 |
| 82. | ... | 313 | 87 $M_3$ 2d G. S., 1879-80, | 2.190 | 1.310 | 95.232 | 0.407 | ... | 0.139* | ... | 0.722 |
| 83. | ... | 314 | 87 $M_3$ 2d G. S., 1879-80, | 1.960 | 1.060 | 95.532 | 0.930 | ... | 0.160* | ... | 0.368 |
| 84. | ... | 315 | 87 $M_3$ 2d G. S., 1879-80, | 1.780 | 1.529 | 95.196 | 1.265 | ... | 0.185* | ... | 0.045 |
| 85. | ... | 316 | 87 $M_3$ 2d G. S., 1879-80, | 1.110 | 0.867 | 96.428 | 1.202 | ... | 0.053* | ... | 0.340 |
| 86. | ... | 370 | 295 MM 2d G. S., 1876-8, | 37.873 | 3.390† | 34.301 | 21.650 | ... | 0.112* | $FeS_2$ 1.268, | 2.706 |
| 87. | A. S. McCreath, | ... | 77 M 2d G. S., 1874-5, | 2.070 | ... | 93.810 | 1.710 | 0.129* | 0.018* | ... | 2.263 |
| 88. | ... | 351 | 93 $M_3$ 2d G. S., 1879-80, | 2.660 | ... | 95.071 | 1.044 | ... | ... | $FeCO_3$ .261, $CaSO_4$ .744 $H_2O$ & organic matter, .220, | ... |
| 89. | ... | 91a | 365 MM 2d G. S. 1876-8, | 1.052‡ | 0.190 | 87.675* | 1.725* | 0.222 | 0.023 | $FeS_2$ 0.429, $K_2O$ .0116, $H_2O$ 2.190, Carb. matter 6.510, | ... |
| 90. | ... | 780a | 310 MM 2d G. S., 1876-8, | 4.300 | 0.363 | 86.126 | 8.861 | 0.340* | 0.087* | ... | ... |
| 91. | ... | 780b | 310 MM 2d G. S., 1876-8, | 2.508 | 0.600 | 90.625 | 6.167 | 0.200* | 0.060* | ... | ... |
| 92. | ... | 1,018a | 311 MM 2d G. S., 1876-8, | 4.250 | ... | 65.750 | 28.430 | ... | 0.011* | ... | 1.549 |
| 93. | ... | 1,018b | 311 MM 2d G. S., 1876-8, | 7.450 | ... | 79.500 | 11.730 | ... | trace | ... | 1.320 |
| 94. | ... | 1,018c | 311 MM 2d G. S., 1876-8, | 2.550 | ... | 92.000 | 4.540 | ... | trace | ... | 0.910 |
| 95. | ... | 1,018d | 311 MM 2d G. S., 1876-8, | 2.750 | ... | 69.250 | 26.250 | ... | trace | ... | 1.365 |
| 96. | ... | 335 | 91 $M_3$ 2d G. S., 1879-80, | 12.290 | 3.610 | 80.357 | 1.619 | ... | 0.197* | ... | 1.927 |
| 97. | ... | 336 | 91 $M_3$ 2d G. S., 1879-80, | 6.540 | 2.750 | 81.875 | 7.189 | ... | 0.151* | ... | 1.495 |
| 98. | ... | 337 | 91 $M_3$ 2d G. S., 1879-80, | 13.680 | 4.835 | 69.257 | 9.308 | ... | 0.176* | ... | 2.644 |
| 99. | ... | 338 | 91 $M_3$ 2d G. S., 1879-80, | 21.250 | 7.940 | 57.321 | 8.854 | ... | 0.087* | ... | 4.548 |
| 100. | ... | 339 | 91 $M_3$ 2d G. S., 1879-80, | 2.390 | 2.205 | 86.910 | 6.659 | ... | 0.039* | ... | 1.797 |
| 101. | ... | 340 | 91 $M_3$ 2d G. S., 1879-80, | 7.370 | 2.610 | 86.214 | 1.785 | ... | 0.115* | ... | 1.906 |
| 102. | ... | 341 | 91 $M_3$ 2d G. S., 1879-80, | 3.370 | 1.710 | 91.785 | 1.808 | ... | 0.074* | ... | 1.253 |
| 103. | ... | 347 | 92 $M_3$ 2d G. S., 1879-80, | 36.860 | 7.040 | 50.357 | 2.467 | ... | 0.124* | ... | 3.152 |
| 104. | ... | 342 | 92 $M_3$ 2d G. S., 1879-80, | 61.670 | 3.830 | 27.857 | 0.983 | ... | 0.142* | ... | 5.518 |
| 105. | ... | 343 | 92 $M_3$ 2d G. S., 1879-80, | 38.950 | 3.030 | 54.553 | 1.135 | ... | 0.238* | ... | 2.094 |
| 106. | ... | 344 | 92 $M_3$ 2d G. S., 1879-80, | 41.690 | 3.650 | 49.732 | 1.331 | ... | 0.545* | ... | 3.052 |
| 107. | ... | 345 | 92 $M_3$ 2d G. S., 1879-80, | 1.630 | 1.638 | 94.357 | 1.684 | ... | 0.071* | ... | 0.670 |
| 108. | ... | 346 | 92 $M_3$ 2d G. S., 1879-80, | 2.200 | 1.625 | 94.107 | 1.369 | ... | 0.144* | ... | 0.554 |
| 109. | ... | 348 | 92 $M_3$ 2d G. S., 1879-80, | 8.390 | 3.422 | 85.714 | 1.171 | ... | 0.158* | ... | 1.145 |
| 110. | ... | 349 | 92 $M_3$ 2d G. S., 1879-80, | 50.670 | 10.070 | 36.785 | 1.408 | ... | ... | ... | 1.067 |
| 111. | ... | 350 | 93 $M_3$ 2d G. S., 1879-80, | 15.980 | 3.680 | 76.143 | 1.740 | ... | ... | ... | 2.457 |
| 112. | A. S. McCreath, | ... | 77 M 2d G. S., 1874-5, | 16.130 | ... | 66.912 | 9.836 | 0.295* | 0.165* | ... | 16.662 |
| 113. | A. S. McCreath, | ... | 77 M 2d G. S., 1874-5, | 53.330 | ... | 36.764 | 2.011 | trace | 0.071* | ... | 7.914 |
| 114. | W. S. Sweetser, | 29,982 | Pa. Expt. Station records, | 5.650 | ... | 89.870 | 1.320 | ... | ... | ... | 3.160 |

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*Recalculated. †$Al_2O_3$ only.

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 149. | .... | 775 | 294 MM 2d G. S., 1876-8, | 15.060 | 7.380 | 58.750 | 16.006 | 0.108* | 0.195* | .... | 2.507 |
| 150. | .... | 767 | 294 MM 2d G. S., 1876-8, | 13.790 | 3.540 | 78.768 | 3.421 | 0.243* | 0.041* | .... | 1.197 |
| 151. | .... | .... | 288 MM 2d G. S., 1876-8, | 12.160 | 3.020 | 79.821 | 3.001 | 0.293* | 0.041* | .... | 1.064 |
| 152. | .... | 20,910 | Pa. Expt. Station Records, | 36.060 | .... | 59.020 | 1.220 | .... | .... | .... | 3.700 |
| 153. | .... | 20,911 | Pa. Expt. Station Records, | 41.940 | .... | 52.970 | 1.090 | .... | .... | .... | 5.000 |
| 154. | .... | 20,912 | Pa. Expt. Station Records, | 20.910 | .... | 21.590 | 2.920 | .... | .... | .... | 54.580 |
| 155. | A. N. Diehl, | 32,454 | Pa. Expt. Station Records, | 4.860 | 3.100 | 83.880 | 8.190 | .... | .... | .... | .... |
| 156. | A. N. Diehl, | 32,455 | Pa. Expt. Station Records, | 11.450 | 1.250 | 83.690 | 2.760 | .... | .... | .... | 0.800 |
| 157. | A. N. Diehl, | 32,456 | Pa. Expt. Station Records, | 13.910 | 2.650 | 76.120 | 6.300 | .... | .... | .... | 0.770 |
| 158. | C. P. Beistle, | 32,412 | Pa. Expt. Station Records, | 2.160 | .... | 95.030 | .... | .... | .... | .... | 2.160 |
| 159. | .... | 317 | 87 M₃ 2d G. S., 1879-80, | 2.390 | 1.530 | 92.500 | 2.497 | .... | 0.053* | .... | 1.030 |
| 160. | .... | 318 | 87 M₃ 2d G. S., 1879-80, | 9.780 | 4.230 | 75.357 | 9.330 | .... | 0.039* | .... | 1.264 |
| 161. | .... | 319 | 87 M₃ 2d G. S., 1879-80, | 11.780 | 3.790 | 77.143 | 4.691 | .... | 0.167* | .... | 2.429 |
| 162. | .... | 320 | 88 M₃ 2d G. S., 1879-80, | 6.170 | 2.140 | 89.107 | 1.611 | .... | 0.065* | .... | 0.917 |
| 163. | .... | 321 | 88 M₃ 2d G. S., 1879-80, | 16.660 | 7.250 | 48.571 | 23.762 | .... | 0.074* | .... | 3.683 |
| 164. | .... | 322 | 88 M₃ 2d G. S., 1879-80, | 3.480 | 1.285 | 90.000 | 2.860 | .... | 0.025* | .... | 2.350 |
| 165. | .... | 323 | 88 M₃ 2d G. S., 1879-80, | 3.130 | 1.312 | 91.875 | 2.421 | .... | 0.028* | .... | 1.234 |
| 166. | .... | 324 | 88 M₃ 2d G. S., 1879-80, | 6.770 | 1.740 | 88.928 | 1.589 | .... | 0.053* | .... | 0.920 |
| 167. | .... | 325 | 88 M₃ 2d G. S., 1879-80, | 8.400 | 2.170 | 87.035 | 1.558 | .... | 0.131* | .... | 0.706 |
| 168. | .... | 326 | 88 M₃ 2d G. S., 1879-80, | 2.070 | 2.320 | 92.857 | 1.680 | .... | 0.044* | .... | 1.029 |
| 169. | .... | 327 | 89 M₃ 2d G. S., 1879-80, | 33.900 | 7.790 | 51.410 | 3.962 | .... | 0.076* | .... | 2.862 |
| 170. | .... | 328 | 89 M₃ 2d G. S., 1879-80, | 8.020 | 4.653 | 82.393 | 1.891 | .... | 0.687* | .... | 2.356 |
| 171. | .... | 329 | 89 M₃ 2d G. S., 1879-80, | 1.910 | 1.315 | 94.392 | 1.702 | .... | 0.071* | .... | 0.610 |
| 172. | .... | 330 | 89 M₃ 2d G. S., 1879-80, | 2.040 | 1.310 | 93.643 | 1.816 | .... | 0.069* | .... | 1.122 |
| 173. | .... | 331 | 89 M₃ 2d G. S., 1879-80, | 1.300 | 0.990 | 96.428 | 0.908 | .... | 0.078* | .... | 0.296 |
| 174. | .... | 332 | 90 M₃ 2d G. S., 1879-80, | 1.280 | 0.780 | 96.578 | 0.832 | .... | 0.085* | .... | 0.445 |
| 175. | .... | 333 | 90 M₃ 2d G. S., 1879-80, | 51.450 | 4.760 | 39.428 | 1.816 | .... | 0.094* | .... | 2.452 |
| 176. | .... | .... | 78 Catalogue of Exhibits, | 3.200 | .... | 59.520* | 36.920* | .... | .... | .... | 3.600 |
| 177. | .... | .... | 79 Catalogue of Exhibits, | 7.000 | .... | 86.000 | 7.000 | .... | .... | .... | .... |
| 178. | .... | .... | 80 Catalogue of Exhibits, | .... | .... | .... | 36.900 | .... | .... | .... | 0.360 |
| 179. | .... | 779 | 309 MM 2d G. S., 1876-8, | 0.436 | 0.517 | 54.750 | 44.204 | 0.028* | 0.023* | .... | 0.042 |
| 180. | .... | 778a | 309 MM 2d G. S., 1876-8, | 0.847 | 0.304 | 55.104 | 43.602 | 0.068* | 0.037* | .... | 0.048 |
| 181. | .... | 778b | 309 MM 2d G. S., 1876-8, | 1.926 | 0.869 | 53.517 | 43.522 | 0.053* | 0.032* | .... | 0.081 |
| 182. | .... | 778c | 309 MM 2d G. S., 1876-8, | 7.699 | 0.731 | 50.339 | 41.143 | 0.075* | 0.066* | .... | .... |
| 183. | .... | 747 | 297 MM 2d G. S., 1876-8, | 2.790 | 0.805 | 94.214 | 1.739 | 0.413* | 0.046* | .... | .... |
| 184. | .... | 748 | 297 MM 2d G. S., 1876-8, | 1.970 | 0.632 | 95.768 | 1.097 | 0.220* | 0.039* | .... | 0.274 |
| 186. | .... | 746 | 297 MM 2d G. S., 1876-8, | 3.070 | 1.563 | 93.340 | 1.460 | 0.308* | 0.108* | .... | 0.151 |
| 187. | .... | .... | 297 MM 2d G. S., 1876-8, | 2.080 | 1.187 | 94.785 | 1.369 | 0.308* | 0.078* | .... | 0.188 |
| 188. | M. E. McDonnell, | 20,759 | .... | 7.000* | 1.000* | 85.000* | 7.000* | .... | .... | .... | .... |
| 188. | M. E. McDonnell, | 20,759 | Pa. Expt. Station Records, | 20.120 | 2.120 | 76.130 | 1.300 | .... | .... | .... | 0.330 |
| 189. | Atlas Hercules and Cement Co., | .... | .... | 6.000§ | .... | 92.000 | 1.000 | .... | .... | K₂O 1.00, | .... |
| 190. | .... | 65 | 309 MM 2d G. S., 1876-8, | 8.980 | 0.070† | 49.316 | 40.463 | .... | 0.014* | FeCO₃, 1.035, FeS₂ .030, Carb. matter 0.250, | .... |
| 191. | .... | 66 | 309 MM 2d G. S., 1876-8, | 10.750 | 0.140† | 51.558 | 35.216 | .... | 0.041* | FeCO₃ 1.450, FeS₂ .611, Carbon. matter 0.210, | 0.024 |
| 192. | .... | 67 | 309 MM 2d G. S., 1876-8, | 8.400 | 0.065† | 86.036 | 4.594 | .... | 0.087* | FeCO₃ 0.538, FeS₂ .268, Carbon. matter 0.420, | .... |

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*Recalculated. †$Al_2O_3$ only §Includes insoluble, ferric oxid and alumina.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 193. | ........ | 68 | 310 MM 2d G. S., 1876-8, ........ | 11.070 | 0.860† | 70.750 | 15.256 | ........ | 0.044* | $FeCO_3$ 1.398, $FeS_2$ .105, Carbon. matter, 0.120, ........ | 0.467 |
| 194. | ........ | 69 | 310 MM 2d G. S., 1876-8, ........ | 10.930 | 0.300† | 56.220 | 31.201 | ........ | 0.011* | $FeCO_3$ 1.305, $FeS_2$ .320, Carbon matter 0.120, ........ | ........ |
| 195. | D. McCreath, ........ | 392 | 76 M 2d G. S., 1874-5, ........ | 7.850 | ........ | 83.632 | 5.463 | ........ | 0.060* | $FeCO_3$ 1.188, $FeS_2$ .238, Carbon matter, 0.235, ........ | 0.735 |
| 196. | A. S. McCreath, ........ | ........ | 76 M 2d G. S., 1874-5, ........ | 5.650 | ........ | 51.920 | 41.071 | trace | 0.025* | ........ | 1.334 |
| 197. | A. S. McCreath, ........ | ........ | 76 M 2d G. S., 1874-5, ........ | 11.280 | ........ | 47.890 | 39.585 | trace | 0.048* | ........ | 1.217 |
| 198. | A. S. McCreath, ........ | ........ | 76 M 2d G. S., 1874-5, ........ | 12.490 | ........ | 51.603 | 33.917 | 0.363* | 0.027* | ........ | 1.595 |
| 199. | A. S. McCreath, ........ | ........ | 76 M 2d G. S., 1874-5, ........ | 9.240 | ........ | 48.630 | 40.410 | 0.013* | 0.027* | ........ | 1.680 |
| 200. | Dr. Genth, ........ | ........ | 105 2d G. S., 1874-5, ........ | ........ | 2.360* | 50.076* | 43.150 | ........ | ........ | $SO_2$ 3.08, $Fe_2O_3$ 0.67 MnO 0 35, ........ | 0.314 |
| 201. | Dr. Genth, ........ | ........ | 105 2d G. S., 1874-5, ........ | ........ | 0.700* | 52.470* | 42.800 | ........ | ........ | $SO_2$ 1.12, $Fe_2O_3$ 1.21, MnO 0.44, ........ | 1.260 |
| 202. | H. Pemberton, Jr., ........ | ........ | 110 2d G. S., 1874-5, ........ | ........ | 1.180† | 48.250* | 36.870 | ........ | ........ | $SO_2$ 12.13, $Fe_2O_3$ 0.88 | ........ |
| 203. | ........ | 352 | 94 $M_3$ 2d G. S., 1879-80, ........ | 4.680 | 4.660 | 70.589 | 1.740 | 0.068* | trace | ........ | 1.263 |
| 204. | ........ | 353 | 94 $M_3$ 2d G. S., 1879-80, ........ | 6.960 | 1.330 | 60.964 | 30.691 | 0.250* | 0.007* | ........ | ........ |
| 205. | ........ | 354 | 94 $M_3$ 2d G. S., 1879-80, ........ | 5.570 | 1.600 | 72.156 | 20.304 | 0.418* | 0.011* | ........ | ........ |
| 206. | S. S. Hartranft, ........ | 784 | 308 MM 2d G. S., 1876-8, ........ | 0.760 | 0.426 | 97.651 | 1.131 | 0.095* | 0.069* | ........ | ........ |
| 207. | S. S. Hartranft, ........ | 783 | 308 MM 2d G. S., 1876-8, ........ | 4.530 | 1.253 | 81.178 | 13.396 | 0.135* | 0.057* | ........ | ........ |
| 208. | ........ | 781 | 308 MM 2d G. S., 1876-8, ........ | 4.060 | 1.360 | 70.214 | 24.415 | 0.095* | 0.037* | ........ | ........ |
| 209. | ........ | 782 | 308 MM 2d G. S., 1876-8, ........ | 8.010 | 1.422 | 54.285 | 36.109 | 0.378* | 0.025* | ........ | ........ |
| 210. | McCreath, ........ | ........ | ........ | 2.850 | 0.700 | 94.290 | 1.530 | 0.140 | 0.030 | ........ | 0.460 |
| 211. | ........ | ........ | ........ | 0.250 | 0.900 | 53.190 | 45.450 | ........ | 0.020 | ........ | 0.190 |
| 212. | ........ | ........ | 79 Catalogue of Exhibits, ........ | ........ | ........ | 52.000 | 46.000 | ........ | ........ | $SO_2$ 1.000, ........ | 2.000 |
| 213. | G. G. Pond, ........ | ........ | 81 Catalogue of Exhibits, ........ | ........ | 0.170† | 98.160 | 1.080* | ........ | 0.050 | $SO_3$ 0.77, FeO 054, . | ........ |
| 214. | ........ | 286 | 82 $M_3$ 2d G. S., 1879-80, ........ | 31.520 | 5.384 | 60.214 | 1.664 | ........ | 0.155* | ........ | 1.063 |
| 215. | ........ | 287 | 82 $M_3$ 2d G. S., 1879-80, ........ | 41.940 | 5.761 | 49.178 | 1.816 | ........ | 0.120* | ........ | 1.185 |
| 216. | ........ | 288 | 82 $M_3$ 2d G. S., 1879-80, ........ | 53.810 | 8.298 | 33.482 | 1.967 | ........ | 0.192* | ........ | 2.251 |
| 217. | ........ | 280 | 82 $M_3$ 2d G. S., 1879-80, ........ | 15.720 | 2.550 | 71.732 | 7.621 | ........ | 0.030* | ........ | 2.347 |
| 218. | ........ | 290 | 82 $M_3$ 2d G. S., 1879-80, ........ | 6.530 | 1.206 | 89.642 | 1.816 | ........ | 0.025* | ........ | 0.781 |
| 219. | ........ | 398 | 295 MM 2d G. S., 1876-8, ........ | 24.780 | 4.393 | 63.969 | 4.244 | 0.963* | 0.325* | Fe as carbonate, ... | 1.326 |

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†$Al_2O_3$ only.

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 220. | ........ | 394 | 295 MM 2d G. S., 1876-8, ........ | 6.040 | 2.972 | 86.778 | 2.908 | 0.415* | 0.304* | Fe as carbonate,... | 0.582 |
| 221. | ........ | 418 | 295 MM 2d G. S., 1876-8, ........ | 5.640 | 0.340† | 88.139 | 1.854 | 0.393* | 0.053* | FeCO$_3$ 1.796,........ | 1.282 |
| 222. | ........ | 407 | 295 MM 2d G. S., 1876-8, ........ | 4.970 | 2.693 | 79.478 | 10.222 | 0.420* | 0.078* | Fe as carbonate,... | 1.129 |
| 223. | ........ | 418a | 295 MM 2d G. S., 1876-8, ........ | 2.950 | .359† | 92.296 | 1.483 | 0.243* | 0.041* | FeCO$_3$ 1.167, Carb. matter .550,........ | ....... |
| 224. | ........ | 419b | 295 MM 2d G. S., 1876-8, ........ | 12.020 | 1.626† | 54.321 | 23.088 | 0.318* | 0.117* | FeCO$_3$ 8.492, Carb. matter .980,........ | ....... |
| 225. | ........ | 419c | 295 MM 2d G. S., 1876-8, ........ | 10.760 | .403† | 69.264 | 13.773 | 0.265* | 0.108* | FeCO$_3$ 4.739, Carb. matter .590,........ | 0.098 |
| 226. | ........ | 83 | 296 MM 2d G. S., 1876-8, ........ | 17.770 | 4.440* | 32.940 | 16.060 | 0.220* | 0.133* | FeCo$_3$ 5.800, ........ | 2.637 |
| 227. | ........ | 424 | 296 MM 2d G. S., 1876-8, ........ | 3.850 | 0.261† | 90.544 | 2.134 | 1.160* | 0.080* | FeCO$_3$ 1.508, ....... | 0.518 |
| 228. | ........ | 84 | 296 MM 2d G. S., 1876-8, ........ | 13.360 | 11.600 | 50.160 | 18.494 | 0.383* | 0.275* | Fe as carbonate,... | 5.728 |
| 229. | ........ | 462 | 290 MM 2d G. S., 1876-8, ........ | 20.660 | 1.700† | 64.706 | 2.156 | 6.078* | 1.820* | Fe 4.274, Carb. matter 2.602, ........ | ....... |
| 230. | ........ | 380 | 291 MM 2d G. S., 1876-8, ........ | 3.740 | 1.986 | 90.803 | 2.738 | 0.210* | 0.110* | Fe as carbonate,... | 0.413 |
| 231. | ........ | 587 | 291 MM 2d G. S., 1876-8, ........ | 19.800 | 2.886† | 55.589 | 14.224 | 0.463* | 0.073* | FeCO$_3$ 6.835, ...... | 0.130 |
| 232. | ........ | 427 | 291 MM 2d G. S., 1876-8, ........ | 2.500 | 0.224† | 89.522 | 5.327 | 0.613* | 0.037* | FeCO$_3$ 1.812, ...... | ....... |
| 223. | ........ | 464 | 289 MM 2d G. S., 1876-8, ........ | 4.040 | 1.825 | 86.625 | 6.152 | 0.283* | 0.053* | Fe as carbonate, ... | 1.073 |
| 234. | ........ | 584 | 366 MM 2d G. S., 1876-8, ........ | 37.940 | 3.317 | 51.921 | 3.639 | 0.203* | 0.234* | Mn$_3$O$_4$ 0.586, FeCO$_3$ 3.069, ........ | ....... |
| 235. | ........ | 404 | 366 MM 2d G. S., 1876-8, ........ | 4.803 | 0.455 | 80.588 | 8.445 | .......... | 0.060* | MnCO$_3$ 1.400 FeCO$_3$ 3.314, FeS$_2$ 2.371,. | 0.564 |
| 236. | D. McCreath,........ | 448 | 286 MM 2d G. S., 1876-8, ........ | 9.180 | 3.211 | 72.623 | 12.614 | 0.398* | 0.011* | ........ | 1.963 |
| 237. | D. McCreath,........ | 540 | 286 MM 2d G. S., 1876-8, ........ | 6.220 | 2.871 | 85.732 | 5.098 | 0.260* | 0.085* | ........ | ....... |
| 238. | D. McCreath,........ | ........ | 287 MM 2d G. S., 1876-8, ........ | 9.730 | 5.301 | 69.160 | 15.535 | 0.115* | 0.039* | ........ | 0.12 |
| 239. | D. McCreath,........ | ........ | 287 MM 2d G. S., 1876-8, ........ | 11.510 | 6.830 | 74.803 | 6.734 | 0.120* | 0.160* | ........ | ....... |
| 240. | ........ | 923 | 300 MM 2d G. S., 1876-8, ........ | 5.240 | 5.196 | 80.398 | 5.653 | 0.600* | 0.305* | MnCO$_3$ 3.116, ...... | ....... |
| 241. | ........ | 924 | 300 MM 2d G. S., 1876-8, ........ | 17.850 | 5.870 | 60.000 | 5.387 | 0.230* | 0.330* | MnCO$_3$ 1.689, ...... | ....... |
| 242. | ........ | 336 | 299MM 2d G. S., 1876-8, ........ | 41.700 | 4.411 | 51.520* | 2.291* | 0.087 | 0.729 | ........ | ....... |
| 243. | A. S. McCreath,...... | ........ | 388 K 2d G. S., 1875, ........ | 22.520 | 7.148 | 48.823 | 20.621 | 0.507* | 0.117* | ........ | 0.264 |
| 244. | D. McCreath,........ | ........ | 388 K 2d G. S., 1875, ........ | 15.750 | 7.511 | 47.080 | 28.528 | 0.173* | 0.291* | ........ | 0.667 |
| 245. | D. McCreath,........ | ........ | 388 K 2d G. S., 1875, ........ | 13.300 | 3.306 | 68.837 | 14.649 | 0.245* | 0.112* | ........ | ....... |
| 246. | D. McCreath,........ | ........ | 388 K 2d G. S., 1875, ........ | 14.920 | 5.618 | 47.750 | 30.943 | 0.315* | 0.084* | ........ | 0.420 |
| 247. | D. McCreath,........ | ........ | 388 K 2d G. S., 1875, ........ | 17.380 | 2.929 | 72.866 | 3.813 | 0.388* | 0.140* | ........ | 3.484 |
| 248. | ........ | 355 | 94 M$_2$ 2d G. S., 1879-80, ........ | 28.800 | 4.145 | 64.392 | 1.816 | .......... | 0.115* | ........ | 0.782 |
| 249. | ........ | 356 | 94 M$_2$ 2d G. S., 1879-80, ........ | 65.470 | 8.903 | 19.785 | 3.518 | .......... | 0.217* | ........ | 2.107 |
| 250. | ........ | 357 | 94 M$_2$ 2d G. S., 1879-80, ........ | 75.220 | 4.432 | 17.696 | 1.589 | .......... | 0.078* | ........ | 0.335 |
| 251. | ........ | 358 | 94 M$_2$ 2d G. S., 1879-80, ........ | 80.950 | 4.988 | 11.196 | 1.664 | .......... | 0.083* | ........ | 1.119 |
| 252. | ........ | 763 | 293 MM 2d G. S., 1876-8, ........ | 4.015 | 1.520 | 91.982 | 1.664 | 0.228* | 0.027* | ........ | 0.564 |
| 253. | ........ | 948 | 293 MM 2d G. S., 1876-8, ........ | 0.990 | 2.720 | 94.648 | 1.144 | 0.070* | 0.034* | ........ | 0.399 |
| 254. | D. McCreath,........ | 546 | 347 MM 2d G. S., 1876-8, ........ | 38.240 | 6.002† | 42.357 | 4.037 | 1.265* | 1.351* | FeCO$_3$ 4.142, ....... | 3.606 |
| 255. | ........ | ........ | 80 Catalogue of Exhibits, ........ | 3.000 | .......... | 97.100 | 2.600 | .......... | .......... | ........ | ....... |
| 256. | A. S. McCreath,...... | ........ | 77 M 2d G. S., 1874, ........ | 21.500 | ‡0.743* | 73.180 | 4.370 | .......... | .......... | ........ | 0.207 |
| 257. | A. S. McCreath,...... | ........ | 77 M 2d G. S., 1874, ........ | 20.060 | ‡7.526* | 62.350 | 6.320 | .......... | .......... | ........ | 3.744 |
| 258. | A. S. McCreath,...... | ........ | 77 M 2d G. S., 1874, ........ | 15.890 | ‡1.899* | 77.890 | 2.830 | .......... | .......... | ........ | 1.491 |
| 259. | A. S. McCreath,...... | ........ | 77 M 2d G. S., 1874, ........ | 4.300 | ‡0.428* | 93.870 | 0.960 | .......... | .......... | ........ | 0.442 |
| 260. | L. De L. Moro, ...... | ........ | 110 C 2d G. S., 1874, ........ | 5.650 | †2.070 | 66.790 | 31.460 | .......... | .......... | SO$_3$ 0.30, FeO 0.37, | ....... |
| 261. | ........ | 339 | 306 MM 2d G. S., 1876-8, ........ | 16.650 | 2.034 | 65.702* | 10.298* | trace | 0.132 | H$_2$O 0.250, MnO 0.321, FeCO$_3$ 3.933*, FeS$_2$ .065, ........ | 0.515 |

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*Recalculated. †Al$_2$O$_3$ only. ‡Fe$_2$O$_3$ only.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 262. | .......................... | 481 | 308 MM 2d G. S., 1876-8, .............. | 18.210 | 7.454 | 68.707* | 1.670* | trace | 0.060 | $FeCO_3$ 3.587*, $FeS_2$ 0.41, $H_2O$ 1.055, ... | ....... |
| 263. | .......................... | 273 | 79 $M_3$ 2d G. S., 1879-80, .............. | 14.010 | 2.400† | 80.217* | 10.822* | 0.010* | 0.025* | FeO 1.1794, ......... | ....... |
| 264. | .......................... | 274 | 79 $M_3$ 2d G. S., 1879-80, .............. | 10.890 | 2.320† | 78.915* | 13.138* | 0.008* | 0.028* | FeO 0.0864, ......... | ....... |
| 265. | .......................... | 275 | 79 $M_3$ 2d G. S., 1879-80, .............. | 10.460 | 1.690† | 83.875* | 7.899* | 0.010* | 0.007* | FeO 0.585, .......... | ....... |
| 266. | .......................... | 276 | 79 $M_3$ 2d G. S., 1879-80, .............. | 18.580 | 2.680† | 76.630* | 6.247* | 0.008* | 0.030* | FeO 1.098, .......... | ....... |
| 267. | .......................... | 277 | 79 $M_3$ 2d G. S., 1879-80, .............. | 27.010 | 5.090† | 78.379* | 6.010* | 0.018* | 0.071* | FeO 2.804, .......... | ....... |
| 268. | Franklin Menges, .. | ........ | .......................................... | 0.530 | 0.030 | 83.120 | 8.230 | .......... | 0.100 | $K_2CO_3$ 4.23, ....... | 0.560 |
| 269. | .......................... | 25,616 | Pa. Expt. Station Records, .......... | 0.560 | 1.440 | 98.350 | 0.160 | .......... | .......... | ........................ | ....... |
| 270. | .......................... | 25,617 | Pa. Expt. Station Records, .......... | 0.460 | 2.360 | 94.120 | 1.850 | .......... | .......... | ........................ | 1.210 |
| 271. | .......................... | 25,618 | Pa. Expt. Station Records, .......... | 6.420 | 0.600 | 91.480 | 0.900 | .......... | .......... | ........................ | 0.600 |
| 272. | .......................... | 25,619 | Pa. Expt. Station Records, .......... | 19.350 | 1.460 | 78.570 | 1.090 | .......... | .......... | ........................ | ....... |
| 273. | .......................... | 25,626 | Pa. Expt. Station Records, .......... | 4.910 | 3.490 | 80.960 | 9.620 | .......... | .......... | ........................ | |

*Recalculated. †$Al_2O_3$ only

# ANALYSES OF ROSE SOILS.

BY WILLIAM FREAR AND CHARLES P. BEISTLE.

All species of domesticated plants possess, as an essential condition to domestication, the power of adapting themselves to a wide variety of circumstances. It is recognized, however, with reference to all such plants that their manner of development, the relative shape and colors of their organs and their vigor of growth are affected by their surroundings and, in particular, by the soil in which they grow.

The rose shows itself by its very wide distribution to be capable in a large measure of adaptation to its surroundings; so that there are few who desire to use this ornamental plant and find themselves unable to secure its development with some satisfaction in the garden beds at their disposal. Florists nevertheless recognize that this plant is very sensitive to the influence of the soil in which it grows and that it is very necessary to exercise care in the selection and mixing of soils for the greenhouse bench when fine blooms are sought. While authorities in rose culture do not agree precisely as to the best soil for rose culture, they agree universally that an excessively cold clay soil, on the one hand, is injurious and that, on the other, a very light sandy soil, and in England, the chalky soils are not at all fitted for a growth of this plant. As to the influence of the mechanical texture of the soil, Peter Henderson (Practical Floriculture, page 119), says that in a stiff clay loam, flowers of more substance and depth of color will be produced than in that of a light and sandy character. Taft (Green House Management, page 5), says, "that while considerable clay is desirable in soil for roses, there is danger from its being too heavy, as even in shallow benches, if the soil at any time becomes too wet * * * * * it will not only be longer in drying out than a lighter soil but 'black spot' and other diseases will be much more likely to follow." Shirley Hibberd (Amateur's Rose Book, pages 14 to 20), says that the standard or brier rose requires a deep loam and will thrive on well cultivated clay or good peat, but will scarcely live on chalk or sand. Dwarfs, whether on their own roots or budded, require a rather light rich loam. Speaking of the soil requirements of the different types of roses, he states that the Moss and Provence varieties thrive in poor soils, that the Chinas and Teas like a rather light soil, but that Perpetuals and Bourbons need a thoroughly good soil of a substantial nature. It appears that there are exceptions in this numerous family of flowering plants to the general rule, that the rose will not thrive upon a wet soil; the barberry-leafed rose is found growing abundantly in the salt marshes of Persia.

The sensitiveness of particular varieties of the rose to soil differences is somewhat more interesting from the fact that for benches the soil used is made up very largely of added materials. Taft states that it is generally admitted that a soil for roses should contain decomposed pasture sods and cow manure. The thick fibrous sod which has been rotting for some months is piled up with cow manure in alternate layers using one part of the manure to every four to six parts of the sod, according to the character of each, adding clay if the soil was light or sand if the soil was heavy.

In view of the foregoing facts, an examination of certain samples of rose soils was undertaken at the request of the Floral Exchange of Philadelphia. The samples were three in number, namely No. 1 (Station No. 32,458), from the grounds of the Floral Exchange at Edgely, Pa., three miles above Bristol, on the Delaware river. The land lies low and the soil is gravelly or light, with large boulders appearing on the surface indicating the glacial origin of the soil. The water-table during the growing season is only two or three feet below the surface. Mr. H. C. Geiger, of the Floral Exchange, states that there are on this farm four acres of land having a clay foundation and that it is upon this soil that they rely for rose culture. The soil is mixed with pure cow manure and a little bone meal is added. The roses grown at Edgely lack the great luxuriance and vigor of those grown at the Waban conservatories, a description of whose soil is given below, but the "Meteor" rose does excellently well at Edgely, equally well whether grown in solid beds in 8 inches of soil upon 12 inches of ashes, or in raised wooden benches filled with 4 or 5 inches of soil. The plants grow luxuriantly and give plently of buds, but the buds do not have the depth of color found in roses of the same variety growing in the Wilkes-Barre soil, represented by sample No. 3 (Station No. 32,453).

No. 2 (Station No. 32,457), is a soil from the Waban conservatories at Natick, Massachusetts, the most celebrated place for rose culture in America. The country about Natick is described as hilly, but there is no description given of the soil. The plants are grown in solid beds with drainage and in raised benches containing four or five inches of soil. The plants in solid beds are retained for several years, but those in the benches are changed every June. The vigor of growth of the plants is remarkable. The varieties grown are "Bride," Bridesmaid," and "Meteor" (all tea roses), the "American Beauty" (hybrid tea), and also a few of the true hybrid perpetual roses such as the "Jacqueminot," "Brunner" and "Magna Charta."

These samples were submitted to both mechanical and chemical analysis, the work being performed by Mr. Charles P. Beistle, under the direction of the writer.

The mechanical analysis was made according to the Osborne beaker method and the chemical determinations were made in accordance with the methods prescribed by the Association of Official Agricultural Chemists. The so-called "assimilable" potash and phosphoric acid were determined by exposing the soil for one week to a one per cent. solution of citric acid and analysing the materials thus dissolved from the soil.

The results of the mechanical analysis are given in the following table, in terms of the number of parts by weight of particles of a given diameter contained in one hundred parts of the air-dried soil; for convenience the diameters are expressed in fractions of a millimeter, the millimeter being about one-twenty-fifth of an inch.

The samples had all of them been screened before being submitted, there being practically nothing coarser than one millimeter in diameter in any of them.

*Mechanical Analyses of Rose Soils (Per Cent. by Weight).*

| Diameters of Particles. (Millimeters.) | No. 1. (Station No. 32,458) Edgely, Pa. | No. 2. (Station No. 32,457) Waban, Mass. | No. 3. (Station No. 32,453) Wilkes-Barre, Pa. |
|---|---|---|---|
| 1 to .5, | 0.98 | 9.64 | 1.21 |
| .5 to .25, | 2.20 | 8.53 | 1.65 |
| .25 to .05, | 33.33 | 31.28 | 47.15 |
| .05 to .01, | 22.20 | 23.78 | 28.07 |
| Less than .01, | 33.72 | 13.21 | 7.37 |
| Water and other volatile matter, | 6.66 | 13.29 | 14.21 |
| Total, | 99.09 | 99.73 | 99.66 |

To even the casual glance, differences between the three soils are quite apparent, the Waban soil containing more than six times as much as the others, of particles ranging from .25 millimeter upwards in size. The Edgely and Waban soils had about the same quantities of materials ranging from .01 to .25 millimeter in diameter and both these soils exceeded the Wilkes-Barre soil in the quantity of clay also; that is, of particles having a diameter of less than .01 millimeter. It seems probable that the Edgely soil would be considerably more retentive of moisture than either of the others.

While the mechanical analysis reveals the larger proportion of coarser material in the Waban soil, it is not fitted to bring to light any difference that may exist in the arrangement of the particles in the several soils. Aside from any quality depending upon such sort of arrangement of the particles, it would seem that the Edgely soil might be made mechanically more like that of Waban by the addition of one-third to one-fourth of its weight of rather coarse, sandy loam.

The results of the chemical examination are presented in the succeeding table expressed in parts per hundred.

*Chemical Analyses of Rose Soils (Per Cent.).*

| Constituents. | No. 1. Edgely, Pa. (Station No. 32,458) | No. 2. Waban, Mass. (Station No. 32,457) | No. 3. Wilkes-Barre, Pa. (Station No. 32,453) |
|---|---|---|---|
| Moisture (loss at 100° C.), | .56 | 3.52 | 2.20 |
| Other volatile matter: | | | |
| (Loss on ignition), | 6.10 | 9.77 | 12.01 |
| Acid insoluble matter: | | | |
| Sand, clay, etc., | 76.34 | 68.89 | 67.84 |
| Soluble silica, | 7.92 | 7.06 | 9.24 |
| Acid soluble matter: | | | |
| Iron oxid, | 3.64 | 3.56 | 3.00 |
| Alumina, | 4.11 | 5.31 | 4.29 |
| Manganese oxid, | 0.29 | 0.00 | 0.00 |
| Lime, | 0.22 | 0.72 | 0.45 |
| Magnesia, | 0.11 | 0.31 | 0.32 |
| Potash, | 0.28 | 0.26 | 0.26 |
| Soda, | 0.28 | 0.20 | 0.10 |
| Carbonic acid, | 0.032 | 0.082 | 0.069 |
| Phosphoric acid, | 0.120 | 0.270 | 0.210 |
| Sulphuric acid, | 0.140 | 0.260 | 0.410 |
| Chlorin, | 0.007 | 0.015 | 0.008 |
| | 100.149 | 100.227 | 100.407 |
| | .003 | .007 | .004 |
| Deducting oxygen equivalent to chlorin, | 100.146 | 100.220 | 100.403 |

*Additional Determinations.*

| Constituents. | No. 1. Edgely, Pa. (Station No. 32,458) | No. 2. Waban, Mass. (Station No. 32,457) | No. 3. Wilkes-Barre, Pa. (Station No. 32,453) |
|---|---|---|---|
| Humus (by modified Grandeau method), | 2.55 | 4.00 | 5.95 |
| Nitrogen, | 0.136 | 0.259 | 0.309 |
| Proportion of humus in volatile matter, | 41.8 | 40.9 | 49.5 |
| Proportion of nitrogen in humus, | 5.33 | 6.47 | 5.20 |
| Potash, citric acid soluble, | 0.016 | 0.090 | 0.040 |
| Proportion of total potash, | 5.7 | 34.6 | 15.4 |
| Phosphoric acid, citric acid soluble, | 0.015 | 0.17 | 0.043 |
| Proportion of total phos. acid, | 12.5 | 63.0 | 20.5 |
| Coefficient of hygroscopicity, | 2.53 | 4.40 | 4.94 |

These analyses show that the Edgely soil has a good deal less of readily available mineral matter than the soils of the other two places. Concerning the special mineral constituents, it is noted that iron and aluminum are present in very similar quantities in all the soils and that this is likewise true of the total acid-soluble potash, but the results of the examination by means of citric acid show both the Edgely and Wilkes-Barre soils, that of the Edgely in particular, to be inferior to the Waban soil in the proportion of very readily soluble potash. The Edgely soil also contains only about one-half as much acid-soluble phosphoric acid as the other soils and of this a much smaller proportion is in condition for the readiest use by the plants; over one-half of that in the Waban soil one-fifth of that in the Wilkes-Barre soil and only one-eighth of that in the Edgely soil being in most readily assimilable condition. The Edgely soil has only about one-third as much lime and magnesia as is possessed by the other two and is somewhat lacking, as compared with the Waban soil, in sulphates, but the Wilkes-Barre soil surpasses both in these constituents. Considering now the organic matter present, it is observable that the Waban soil lies intermediate between that of Wilkes-Barre and that of Edgely, the latter being considerably less rich in these constituents as well. It is clear then, that, even after making allowances for the difference in the total amount of material at all ready for the plant's use in these several soils, that of Edgely is inferior in all the important fertilizing materials except potash; and in the slight solubility of that constituent.

So little is known as to the specific influence of individual fertilizers or soil ingredients upon the flowering habits of plants that any suggestion of improvement in the soil used for this purpose must be made with caution. The quantities of humus and nitrogen, together with these constituents, of phosphoric acid, may be made more like those of Waban if somewhat larger proportions of cow manure are used in the compost; and somewhat larger additions of raw bone meal or better of acidulated phosphate will tend to give due increase to the quantity of phosphoric acid in the Edgely soil. If the acid proprieties of the soluble phosphate are feared in soils so deficient in carbonate of lime as these soils are, the objection can be readily remedied by the use of a little, thoroughly air-slacked lime well mixed in the soil. This latter addition willalso serve to bring up the lime content more nearly to that of Waban. The use of thoroughly air-slaked lime is recommended for the reason that the use of caustic lime or freshly slaked lime might cause too rapid elaboration of soluble nitrogenous compounds to give the best results in the bloom, although such an elaboration would tend to promote a very rapid, if not the most vigorous growth of stem and leaf. It is worthy also of observation whether the presence of a larger quantity of lime may not lead to a higher color in the bloom, as it is a matter of common opinion among orchardists that fruits take their richest coloring in soils in which lime as well as iron are abundantly present. Owng to its inferior condition, rather than its smaller quantity, the supply of potash should be increased by the use either of German salts or of wood ashes.

Finally, it may be remarked that the power of the Edgely soil to take up moisture from a saturated atmosphere , as indicated by the hygroscopic co-efficients in the above table, is, in spite of its much larger holding of clay, less than that of the other two soils; the co-efficients given corresponding almost exactly to the proportions of true humus and also to those of total volatile matter (not including water lost at 100 degrees C.).

# EFFECT OF VARIOUS SYSTEMS OF FERTILIZING UPON THE HUMUS OF THE SOIL.

BY ENOS H. HESS.*

By the term "humus" is meant the organic matter of the soil, chiefly the remains of earlier vegetation, that has so far developed decay that it no longer exhibits traces of plant structure and is no longer separated from the fine mineral matter of the soil by the processes of sifting to which the sample is subjected, prior to chemical analysis, for the separation of the roots, stubble and gravel.

The favorable influence of the humus upon the physical qualities and the richness of the soil in plant food is so generally appreciated that the importance of such farm management as shall result in its maintenance or increase in the soil is everywhere recognized. In the various forms of lease entered into by owner and tenant, a loss of humus has usually been more carefully guarded against than any other sort of soil deterioration.

Soils subject to constant cultivation and to cropping with plants that leave in the soil very little residue of root and stubble, tend to become impoverished in humus. For just as a billet of wood is mus, as in swampy land, or on forest lands and old meadows and pastures left for decades uncultivated, the humus originally present burned up in the stove, the humus is constantly oxidizing in the soil; only, the process is a slow one, the heat developed is dissipated so rapidly that it cannot intensify, and, in this case, the lower organisms present in the soil enter very largely to aid the decomposition—just as yeast does in oxidizing the sugar of cider when the latter undergoes the alcoholic fermentation and becomes "hard."

When, on the contrary, the air is allowed little access to the humus, as in swampy land, or on forest lands and old meadows and pastures left for decades uncultivated, the humus originally present is only very slowly attacked and is reinforced by additions from the dying roots and stubble or leaves of the grass or forest trees.

On cultivated lands, the system of manuring must obviously exercise considerable influence. When stable manure is the principal fertilizer employed, the reinforcement to the humus supply of the soil is derived not only from the crop residues or root, stubble, etc., but also from the strawy matters of the manure; whereas, when lime, plaster or ordinary commercial fertilizers are employed, no direct addition to humus-forming material is had and any increase that follows must occur solely from an increased quantity of root and stubble left upon the land.

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*Thesis presented for the degree of Bachelor of Science, June 14, 1900. Notes by William Frear appended.

It is generally believed that where mineral manures are used exclusively for a considerable period, the humus diminishes and the soil becomes hard and compact. An instance of this occurred on one of the hay farms near Philadelphia, Pennsylvania, where the farmer grew timothy hay continuously for fifteen years by the use of commercial fertilizers alone. He found the yield of hay was gradually decreasing and had to begin hauling manure from the city to get the land into its original condition. A market gardener of Lancaster county found his soil becoming too hard and compact after having used very heavy applications (1,000 to 1,200 pounds per acre each year) of commercial fertilizers for a dozen or more years, and came to the conclusion that he must either haul manure six miles or resort to green manuring in order to secure a proper mechanical condition. His soil was a heavy clay, and there is no doubt that he applied considerably more nitrogen, phosphoric acid and potash than the crops removed. This injurious mechanical effect would not be found on a sandy soil; and further, it is generally considered that sandy soils respond more freely to commercial fertilizers than clay soils.

Lime may supply humus indirectly by stimulating growth, but it hastens the decomposition of that already in the soil. The loss thus sustained is often greater than the gain due to increased crops. This is especially true where large quantities of quick-lime are applied without corresponding amounts of fertilizers rich in organic matter.

## EXPERIMENTS OF THE GENERAL FERTILIZER SERIES.

It was believed that the effects of the various systems of fertilization might be shown upon the plats of the General Fertilizer Series, which have received continuous treatment upon the same plan for at least sixteen years. The determination of the humus in the soils from plants representing a number of the systems under trial was accordingly undertaken. The plan of the General Series of Fertilizer Experiments is fully presented elsewhere in this annual report. For the purpose of this discussion, the following statements will suffice: The area of each plat is one-eighth of an acre. The crops grown were corn, oats, wheat and grass (one-half clover, one-half timothy). The fertilizers were applied every second year to the corn and wheat, except the lime, which was applied every fourth year to the corn. The corn was cut between the second and third joint, the stover hauled off and the stubble plowed down the following spring for oats. During the first eight years, one crop of grass was cut and the after-math left on the ground and plowed down for corn; but in the last eight years, the after-math was cut and hauled off.

The systems of fertilizer treatment examined were:

I. Cropping without manure.—Sample (1). Taken from the four plats, 1, 14, 24 and 36, in each of the tiers, I, II, III and IV, receiving no fertilizer during the sixteen years of the experiment.

II. Manuring with stable manure and lime.—Sample (2). Taken from plat No. 22 in each tier, which received six tons of yard manure every second year and two tons, or fifty bushels of lime per acre every fourth year. The manure was plowed under and the lime spread on the plowed ground. The lime was received from the Bellefonte quarries, the rock of which contains about 98.5 per cent. of calcium carbonate. The stone lime was put on the plot, slacked with water and spread the following day.

III. Liming corn without manure. Sample (3). Taken from the plat (No. 23 in each tier) receiving two tons of lime per acre every fourth year in the same manner as in No. II.

IV. Treatment with carbonate of lime. Sample (4). Taken from plat No. 34 in each tier, which received two tons of ground limestone per acre every second year, applied broadcast after plowing. The limestone was of the same quality as that used for the production of the lime applied in II and III.

V. Treatment with mineral fertilizers, with nitrate of soda as the source of nitrogen.—Sample (5). Taken from plat No. 28 in each tier which received seventy-two pounds per acre of nitrogen in the form of nitrate of soda, forty-eight pounds of phosphoric acid in the form of dissolved bone-black, and one hundred pounds of potash in the form of muriate of potash. The fertilizer was sown broadcast after plowing and thoroughly cultivated in thereafter.

VI. Treatment with mineral fertilizers, with sulphate of ammonia as the source of nitrogen.—Sample (6). Taken from plat No. 32 in each tier, which received seventy-two pounds per acre of nitrogen in the form of sulphate of ammonia and the same amount of phosphoric acid and potash as in No. V.

### ORGANIC MATTER APPLIED IN YARD MANURE.

During the first eight years, the manure applied in Treatment II was taken from an uncovered barn-yard, but during the last eight, one-half was taken from an uncovered yard and one-half from a covered yard. It was made up of the voidings of well-fed dairy cows, heifers, horses and swine, with enough wheat and oats straw or sawdust to absorb the liquid portions.

Assuming that the manure made in the open yard and covered shed in the summer and winter of 1890, is fairly representative of that used during the several years of the experiment, the analysis reported by Dr. Frear (Proc. Soc. Agric. Sci., 1891-2, 139), indicates an average content of 20.32 per cent of organic matter in the manure applied.

The above average was obtained by taking the average of two chopped samples from the open yard during the summer and two from the open yard during the winter for the first eight years, and of two chopped samples from the covered yard for summer and one for winter for the last eight years. The combined averages of the first and last eight years gave 20.32 per cent. This would be equivalent to 2,438.4 pounds per acre applied in Treatment II every two years, or in sixteen years 9.75 tons of organic matter per acre.

To secure some notion of the proportion which this quantity bears to the entire mass of the soil directly affected, the weight of a measured volume of surface soil, taken to the level of the subsoil at the point selected, was determined. For the computation it has been assumed that the surface soil over the entire area involved in these exepriments had a uniform density to the average depth of nine inches.

A block of soil eight inches square was removed to the subsoil, which was six and three-fourths inches deep; the block was therefore 432 cubic inches or one-fourth cubic foot in volume. It was taken from corn stalk land on the 9th of April, before the soil was stirred. The block weighed 22.06 pounds, or 88.24 pounds per cubic foot. The total moisture, as determined by loss in air-drying and in hot-water-oven, was 22.82 per cent. The dry soil would, therefore, weigh 68.10 pounds. At 68.10 pounds per cubic foot, the total weight of an acre of soil nine inches deep would be 111.24 tons. The 9.75 tons of organic matter would make 8.76 per cent. of this amount; but, as will be seen in a subjoined table, the amount of humus actually found is a little over three per cent. This shows that considerable of the organic matter was destroyed by fermentation and the action of lime.

Method of sampling.—A three-inch wood auger was used to take the samples. Five samples were taken at different points in each plat to the depth of the surface soil, judging by the color. The depth of the surface soil on the several plats ranged from 6 to 13 inches. The average depths were, in inches:

| Treatment. | Tier I. | Tier II. | Tier III. | Tier IV. | All tiers. |
|---|---|---|---|---|---|
| I: Plat 1, | 8.30 | 8.90 | 9.05 | 8.20 | 8.61 |
| 14, | 8.85 | 9.05 | 9.50 | 8.50 | 8.98 |
| 24, | 9.40 | 7.85 | 8.45 | 8.50 | 8.58 |
| 36, | 8.90 | 7.35 | 8.95 | 8.20 | 8.35 |
| | | | | | 8.63 |
| II: Plat 22, | 8.55 | 8.80 | 8.65 | 8.75 | 8.69 |
| III: Plat 23, | 8.75 | 9.05 | 8.25 | 8.80 | 8.71 |
| IV: Plat 34, | 9.05 | 8.40 | 9.40 | 8.30 | 8.79 |
| V: Plat 28, | 9.35 | 9.25 | 9.70 | 9.20 | 9.38 |
| VI: Plat 32, | 9.00 | 8.40 | 10.30 | 9.25 | 9.24 |

The samples were taken November 20-22, 1899, placed in flour sacks and hung to the ceiling of a room in which there was no fire during the winter. The soil was taken out of the sacks, February 24 and 27, thoroughly mixed, and a two-kilogram sample taken of a mixture of the sub-samples from each set of plots. Each sample was put into a quart Millville jar and the cover firmly fastened.

The samples were placed in an air-drying oven for from twelve to twenty-four hours, taken out and allowed to stand in the preparing room of the laboratory at a temperature of 60-70 degrees Fahrenheit for twelve hours or more and then sifted through a one-half millimeter sieve. Numbers 4, 5 and 6 were left in the oven about twelve hours longer than numbers 1, 2 and 3, which, no doubt, accounts for their smaller amount of moisture, which will be noticed later.

The percentages of material separated by the sifting are:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Coarse material above ½ millimeter, | 19.32 | 18.09 | 17.88 | 15.57 | 15.24 | 14.62 |
| Fine soil, | 80.77 | 81.91 | 82.12 | 84.43 | 84.76 | 85.38 |
| Total, | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Numbers 4, 5 and 6 were sifted a little more thoroughly than the rest, which accounts in large measure for the lower percentage of coarse material.

## METHODS OF HUMUS DETERMINATION EMPLOYED.

There is no method known whereby all of the substances forming humus can be dissolved out of a soil and directly determined. The methods now in use either secure the extraction of a certain class of humus materials, or attempt to reach a determination of the total humus present by indirect means. In this investigation, three methods were employed, two indirect and one of partial extraction.

Determination of Moisture. Before a discussion of the methods for humus determination, however, the results obtained in the necessary determination of the hygroscopic moisture in the air-dry soils used for analysis, will be presented.

In this determination, two methods were compared: the ordinary method of drying to constant weight in a water-oven at the temperature of boiling water and a modification of Van Bemmelen's method of drying in a desiccator over sulphuric acid to constant weight.

I. By ordinary method. Two grams of the fine soil were put into watch glasses and heated in a hot-water oven for five hours, cooled and weighed. The samples were then heated in the oven for two hour periods until constant weight was obtained. The amounts of moisture found were:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | Unfertilized. | Manure and lime. | Lime. | Limestone. | Nitrate of soda. | Sulphate of ammonia. |
| Determination a, | 1.20 | 1.31 | 1.14 | .91 | .94 | .99 |
| Determination b, | 1.28 | 1.26 | 1.14 | .92 | .93 | .95 |
| Average, | 1.24 | 1.29 | 1.14 | .92 | .94 | .97 |

The smaller amount of moisture in Nos. 4, 5 and 6 is no doubt due to the samples being left in the air-drying oven about twelve hours longer than the others.

2. By Van Bemmelen's method. This investigator objects to the ordinary method because, at the temperature employed, not only hygroscopic water but also some of the water of crystallization and hydration present in the soil constituents, is driven off, giving too high results. To obviate this error, he dries the sample by exposure to the action of sulphuric acid upon the air surrounding the sample,

causing a gradual transfer of the moisture from the soil to the acid. The modification of his method employed in this work was as follows: Two grams of soil were placed in a vacuum desiccator. The one side of the desiccator was attached to a glass tube which led through a bottle half full of sulphuric acid, and thence to a Chapman aspirator. The other side had a tube attached to it leading into a bottle two-thirds full of sulphuric acid, thence to a second bottle. Thus the air, in passing through the two bottles of sulphuric acid, would have all its moisture removed. The aspirator was opened so that one or two bubbles of air were drawn through the apparatus per minute. The desiccator was set in a dish in which ice constantly was kept during the four days of the trial. By this means a temperature of 55 degrees F., or 13 degrees C., was maintained within the desiccator, the room temperature being 75 degrees F.

*Hygroscopic Moisture Found (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | Unfertilized. | Manure and lime. | Lime. | Limestone. | Nitrate of soda. | Sulphate of ammonia. |
| Determination a, | .48 | .53 | .50 | .43 | .51 | .37 |
| Determination b, | .58 | .62 | .59 | .45 | .53 | .41 |
| Average, | .53 | .58 | .55 | .44 | .52 | .39 |
| Moisture by ordinary method, | 1.24 | 1.29 | 1.14 | .92 | .94 | .97 |

Assuming the results by ordinary method to be 100, the Van Bemmelen results are:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 42.73 | 44.96 | 48.24 | 47.80 | 55.31 | 40.21 |

As a means of determining soil moisture, the Van Bemmelen method is long and difficult.

**Humus Determinations.** I. The Ignition Method.—In this the air-dry soil is burned at a rather high temperature. The loss of weight thus caused is attributed to the removal of organic matter (humus) and water. The latter being determined on another portion of the sample, its percentage is deducted from the total loss by ignition, and the remainder is assumed to represent the proportion of humus present. The details of the process are described as follows:

Five grams of the sample were ignited in a platinum crucible for twenty minutes. The soil was stirred occasionally with a platinum wire and the crucible covered meanwhile. The ignited soil was cooled in a desiccator and weighed. A solution of ammonium carbonate was then added in quantity sufficient to moisten all the soil, after which the sample was placed in the hot-water oven until dry and again heated to dull redness, cooled in the desiccator and weighed. The results obtained were:

### *Loss on Ignition.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | Unfertilized. | Manure and lime. | Lime. | Limestone. | Nitrate of soda. | Sulphate of ammonia. |
| Determination a, ................ | 6.36 | 6.83 | 6.10 | 6.51 | 6.10 | 6.43 |
| Determination b, ................ | 6.19 | 6.91 | 6.13 | 6.53 | 6.22 | 6.30 |
| Determination b, ................ | 6.31 | 6.93 | 6.25 | 6.52 | 6.22 | 6.32 |
| Average, ..................... | 6.29 | 6.89 | 6.16 | 6.52 | 6.18 | 6.35 |

### *Loss on Ignition After Treating With Ammonium Carbonate.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Determination a, ................ | 6.35 | 6.66 | 5.99 | 6.42 | 6.06 | 6.40 |
| Determination b, ................ | 6.19 | 6.69 | 5.94 | 6.33 | 6.22 | *(6.33) |
| Determination c, ................ | 6.18 | 6.64 | 6.17 | 6.33 | 6.18 | 6.22 |
| Average, ..................... | 6.24 | 6.66 | 6.03 | 6.36 | 6.15 | 6.31 |

### *Gain Due to Ammonium Carbonate.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Determination a, ................ | .01 | .17 | .11 | .09 | .04 | .03 |
| Determination b, ................ | .00 | .22 | .19 | .20 | .00 | *(—.03) |
| Determination c, ................ | .13 | .29 | .08 | .19 | .04 | .10 |
| Average, ..................... | .05 | .23 | .13 | .16 | .03 | .04 |

*Not included in average.

In igniting the soil, some of the carbonates, as $CaCO_3$ or $MgCO_3$ may be decomposed. By the addition of the ammonium carbonate, carbonic acid will be taken up and the oxids changed to carbonates. The subsequent light heating drives off the ammonia and excess of carbonic acid. The net loss thus secured represents the organic matter plus the water. The results obtained clearly show the need of using ammonium carbonate where carbonates are present in large quantities. The unfertilized, nitrate of soda and sulphate of ammonia plats increased only slightly in weight, while the plats receiving lime showed a considerable loss of carbonic acid on ignition. One would expect the limestone plat to show the largest difference, but the yard manure shows the greatest loss. Wiley in stating the errors which may occur in the method, says: "In the first place, ignited magnesia, when it has lost its carbon dioxide, does not take this up completely on moistening with ammonium carbonate; in the second place, reactions with the chlorids may take place; and, in the third place, the lime which is in the humus will be converted into calcium carbonate." The last reason may account, in part at least, for the greatest difference occurring in the yard manure and lime plat.

Using the results obtained by ignition with ammonium carbonate and subtracting the water found by the two methods previously described, we have:

*Humus=Loss on Ignition—*$H_2O$ *by Ordinary Determination.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| In water-free soil, ............... | 5.00<br>5.06 | 5.37<br>5.44 | 4.89<br>4.95 | 5.44<br>5.49 | 5.21<br>5.26 | 5.34<br>5.39 |

*Humus=Loss by Ignition—*$H_2O$ *by Van Bemmelen Method.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 5.71 | 6.08 | 5.48 | 5.92 | 5.63 | 5.92 |

## II. Indirect Determination of Humus from the Amount of Organic Carbon in the Soil.

This method has been suggested by Van Bemmelen as more direct than that by loss on ignition and as excluding the errors due to losses of water of hydration, chlorin, sulphur, etc.

The principle upon which this determination is based is that humus contains 58 per cent. of carbon, and thus, by the determination of carbonic acid (which contains 27.27 per cent. of carbon) by absorption from the gases resulting from ignition, the amount of humus can be computed by multiplying the carbonic acid obtained by 0.471. The presence of carbonates in the soil occasions some difficulty in working the combustion method, as a part of their carbon dioxide will, of course, be given up on ignition and be reckoned as derived from humus.

In order to avoid an error from the presence of carbonates decomposable by the combustion method, the carbonic acid driven off by warming with hydrochloric acid was determined before and after the combustion.

### (a) Carbonic Acid in Original Soil.

Twenty grams of the soil were placed in an Erlenmeyer flask, together with 40 c. c. of water and 10 c. c. of hydrochloric acid. The flask was attached to a condenser, and that with two sulphuric acid U tubes and two soda-lime tubes, and a Chapman's air-pump. One hundred and twenty to one hundred and thirty bubbles of gas were allowed to pass through per minute.

After all connections were made, the flask with soil, water and acid was heated gradually to the boiling point and boiling maintained for about one-half minute. The air was then allowed to enter the flask through a valved funnel and pass through the soda-lime tubes for fifteen minutes. The soda-lime tubes were then cooled and weighed. The carbonic acid found in per cent. of air-dry soil was:

*Carbonic Acid (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Determination a, | .0695 | .3835 | .3860 | .4625 | .0590 | .0520 |
| Determination b, | .0740 | .3785 | .3875 | .4725 | .0585 | .0520 |
| Average, | .0718 | .3810 | .3868 | .4675 | .0588 | .0520 |

Calculated to water-free soil (on basis of drying by ordinary method), we have:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | .0727 | .3860 | .3912 | .4718 | .0596 | .0525 |

## (b) Carbonic Acid by Combustion in Oxygen.

An ordinary combustion furnace, thirty inches long, was used for this determination. The combustion tube was five-eighths inches in diameter and extended about an inch beyond each end of the furnace. Half of the tube was filled with black copper oxide. The oxygen was forced through a soda solution to take out all $CO_2$ and through sulphuric acid to take out all moisture. The other end of the tube had a sulphuric acid tube and two soda-lime tubes attached; also a soda-lime tube at the end to prevent any $CO_2$ from entering in the rear of the apparatus. About ten grams of soil were used, which was put into two platinum boats and placed in the combustion tube next to the copper oxide. The tube was heated very gradually, allowing twenty-five to thirty minutes to elapse before all the gas jets were turned on. The heating was continued for two hours. The last half-hour, air was passed through the tube instead of oxygen. The sulphuric acid and soda-lime tubes were allowed to cool and then weighed. The results obtained were:

*Water Collected in $H_2SO_4$ Tube.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5 | No. 6. |
|---|---|---|---|---|---|---|
| Determination a, | 4.22 | 4.68 | 3.71 | 3.99 | 3.96 | 4.19 |
| Determination b, | 4.18 | 4.69 | 3.82 | 4.23 | 4.05 | 3.97 |
| Average, | 4.20 | 4.69 | 3.77 | 4.11 | 4.01 | 4.08 |

Subtracting water obtained at 100 degrees C., we have 2.96, 3.40, 2.63, 3.19, 3.07, 3.11 as the sums of the strongly combined water and that formed by the burning of the humus in the air-dry soil.

*Carbonic Acid Evolved.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Determination a, | 5.90 | 6.48 | 5.34 | 6.04 | 6.19 | 6.33 |
| Determination b, | 5.98 | 6.45 | 5.26 | 6.08 | 6.16 | 6.33 |
| Determination c, | 5.86 | ........... | ........... | ........... | ........... | ........... |
| Average, | 5.91 | 6.47 | 5.30 | 6.06 | 6.18 | 6.33 |

Calculated to water-free soil, we have the following percentages of $CO_2$:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 5.98 | 6.55 | 5.36 | 6.12 | 6.24 | 6.30 |

## (c) Carbonic Acid in Combustion Residue.

After the combustion was made, the soil in the platinum boat was transferred to an Erlenmyer flask and the carbonic acid determined by reaction with hydrochloric acid as before. The results obtained were:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | .090 | .367 | .436 | .469 | .095 | .075 |
| | .104 | .412 | .412 | .339 | .093 | .062 |
| Average, ..................... | .097 | .390 | .424 | .469 | .094 | .069 |

Calculated to water-free soil, these percentages are:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | .098 | .396 | .429 | .473 | .095 | .070 |

The above results are higher than those obtained for the soil before combustion. For ease of comparison, the latter are repeated below in terms of the water-free soil.

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | .073 | .386 | .391 | .472 | .059 | .053 |

The reason for the results being higher in the burned soil than in the original may be:

1st. Any calcium humates present would have been destroyed, the humus forming calcium carbonate which would be decomposed by the hydrochloric acid.

2nd. A strong ordor of chlorin was noticed in the flask containing the soil after the determination of carbonic acid in the burned soil was completed. Some of this chlorin could have passed into the soda-lime tubes forming calcium chlorid. The chlorin odor was not noticed soon enough to provide for its obsorption in a silver nitrate solution. No odor of chlorin was noticed after the determination in the original soil. The amount of chlorin given off might have been quite small and yet a strong odor have been present in the flask on account of the highly odoriferous nature of chlorin gas.

The reason for chlorin being evolved in the burned and not in the original soil may be:

1st. Oxygen may be held mechanically by the soil after the combustion, for the oxygen when heated in the presence of $HCl$ would form water and free chlorin.

2nd. The formation of peroxid of manganese, which would release chlorin, especially when heated.

### Computation of Humus from the Analytical Data.

In order to determine the exact amount of carbon due to the organic matter of the soil, the carbon of the carbonic acid found in the original soil was subtracted from the sum of the carbon found by combustion and by action of $HCl$ on the burned soil, according to the following formulae:

$x$=Carbonic acid from organic matter.
$a$=Carbonic acid in original soil.
$b$=Carbonic acid from combustion.
$c$=Carbonic acid in burned soil.

$$x+a=b+c$$
$$x=(b+c)-a$$

The computation for the water-free soil for each plat is seen below:

*Carbonic Acid.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| b= | 5.98 | 5.55 | 5.36 | 6.12 | 6.24 | 6.39 |
| c= | .098 | .395 | .429 | .478 | .095 | .070 |
| b+c= | 6.078 | 6.045 | 5.789 | 6.593 | 6.335 | 6.460 |
| a= | .078 | .386 | .391 | .472 | .059 | .053 |
| x= | 6.005 | 6.559 | 5.398 | 6.121 | 6.276 | 6.407 |

The corresponding percentages of carbon in the soil are:

*Carbon (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 1.64 | 1.79 | 1.47 | 1.67 | 1.71 | 1.75 |

Assuming the humus to contain 58 per cent. of carbon, according to Wolff, and multiplying the carbon by 1.724 we get the following percentages for this substance:

*Humus (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 2.83 | 3.09 | 2.53 | 2.88 | 2.95 | 3.02 |

Comparing the amount of humus in the water-free soil shown by the two methods used, we have the following:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Ignition, .......................... | 5.06 | 5.44 | 4.95 | 5,49 | 5.26 | 5.39 |
| Combustion, ...................... | 2.83 | 3.09 | 2.53 | 2.88 | 2.95 | 3.02 |

The ratios in the soil free from hygroscopic moisture, of the quantity of humus calculated from the organic carbon to that obtained by the ignition method, the latter being taken as 100, are as follows:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 55.9 | 56.8 | 51.1 | 52.5 | 56.1 | 56.0 |

It will be of interest to consider the relations of the hydrogen to the carbon. As indicated in Note 3, if the assumed composition of the humus is correct, the quantity of water found by the process of combustion should very closely approximate the sum of the water the humus containing five per cent. of hydrogen would yield and the strongly combined water which makes up with the humus, practically the entire loss by ignition of the soil free from hygroscopic moisture. The comparisons for the several soils, free from hygroscopic moisture, are as follows, in per cent.:

*Water of Combination (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Loss on ignition corrected for loss of carbonic acid from carbonates, | 5.06 | 5.44 | 4.95 | 5.49 | 5.26 | 5.39 |
| Humus calculated from organic carbon, | 2.83 | 3.09 | 2.53 | 2.88 | 2.95 | 3.02 |
| Strongly combined water, by difference, | 2.23 | 2.35 | 2.42 | 2.61 | 2.31 | 2.37 |
| Water corresponding to humus as above on basis of 5 per cent. hydrogen, | 1.27 | 1.39 | 1.14 | 1.30 | 1.33 | 1.36 |
| Total water calculated, | 3.50 | 3.74 | 3.56 | 3.91 | 3.64 | 3.73 |
| Water found by combustion, | 2.98 | 3.44 | 2.66 | 3.22 | 3.10 | 3.14 |
| Deficiency of water found, | .52 | .30 | .90 | .69 | .54 | .59 |

There is no close agreement, in any case, between the amount of water calculated by the use of VanBemmelen's formulae and that found by analytical methods.

The discussion of these results will be deferred to a later paragraph.

### III. DIRECT ESTIMATION BY THE GRANDEAU METHOD.

Grandeau found that the black, humified matter of stable manure can be readily dissolved by weak alkali, leaving the less fully decomposed material undissolved. Applying the solvent to soils of known history, he obtained solutions of humus that he came to regard as highly indicative of the available humus in the soil. Only a part of the total humus is obtained by such methods, though it has been proposed to confine the term 'humus' to matter capable of such extraction. Some distinction seems desirable, however, and most chemists adhere to the name by which Grandeau first designated the soluble humus, *matiere noire* (black matter). The soil is first treated with an acid to liberate all humus acids from their compounds with the bases. The method employed was a modification of the Huston-Grandeau process, as follows:

Ten grams of air-dry soil were placed on an asbestos filter in a Gooch crucible and extracted with one per cent. hydrochloric acid until the filtrate gave no reaction with ammonia and ammonium oxalate, showing the removal of iron, aluminum and lime. The soil was then washed with water until the acid was entirely removed. The contents of the crucible were washed into a 1,000 c. c. flask with 500 c. c. of four per cent. ammonia water. The flasks were well shaken at intervals for twenty-four hours, after which they were permitted to stand twelve hours without agitation. Fifty c. c. of the extract was then siphoned off into a platinum crucible and evaporated to dryness on a steam bath, placed in a hot-water oven for two hours, cooled and weighed. The dried residue was ignited for fifteen minutes, cooled and weighed. The difference in the weights before and after ignition was taken to represent the *matiere noire.* The results were:

*Matiere Noire (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| a, | 2.07 | 2.02 | 1.94 | 2.08 | 2.05 | 2.27 |
| b, | 2.18 | 2.06 | 1.91 | 2.10 | 2.25 | 2.51 |
| c, | 2.16 | 2.08 | 1.88 | 2.05 | 2.20 | 2.56 |
| Average, | 2.13 | 2.05 | 1.91 | 2.06 | 2.17 | 2.45 |
| In water-free soil, | 2.16 | 2.08 | 1.93 | 2.08 | 2.19 | 2.47 |

In the above results, it is to be noticed that Nos 2, 3 and 4, the three plats receiving lime compounds, are the lowest, and strange as it may seem, the unfertilized plat is higher by .08 per cent. than the one receiving yard manure and lime.

An excess of active, acid humus will, of course, tend to produce acidity in the soil.

It is generally considered that the growth of sorrel (*Rumex acetosella*) is an indication of a sour soil. Nos. 5 and 6 have, for the past few years, had considerable sorrel, the grass on No. 6 being largely crowded out by the weed. A few plants were observed on No. 1, while on Nos. 2, 3 and 4, none have been observed for several years. The agreement between the presence of a slight excess of *matiere noire* and of the sorrel is a matter of some interest, although the Grandeau method is not adapted to reveal whether or not the soil is actually acid in reaction.

Representing the humus calculated from the organic carbon by 100, the proportions of *matiere noire* which that from the several plats contains, are as follows:

*Proportion of Matiere Noire in Organic Matter.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 76.3 | 67.3 | 76.3 | 72.2 | 74.2 | 81.8 |

### THE NITROGEN OF THE SOIL.

The nitrogen was determined by the Kjeldahl-Scovell method. Ten grams of the sample were used and the determination made according to the above method, as given in the Methods of the Association of Official Agricultural Chemists.

The results obtained were as follows:

*Nitrogen (Per Cent.).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| a, | .1205 | ............ | .1140 | .1346 | .1365 | .1380 |
| b, | .1230 | .1450 | .1155 | .1315 | .1350 | .1365 |
| c, | .1252 | .1448 | .1175 | .1325 | .1379 | .1380 |
| Average, | .1229 | .1449 | .1159 | .1329 | .1365 | .1375 |

The above calculated to water-free soil gives the following:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | .1244 | .1468 | .1172 | .1341 | .1378 | .1388 |

A comparison of the existing nitrogen supply with the amounts added in fertilizers will be of interest.

The average depth of the surface soil as determined by the samples taken is 8.65 inches, but taking 9 inches for all the plats and the weight per cubic foot of water-free soil at 68 pounds, there would be in the first 9 inches of an acre the following amounts of nitrogen in pounds:

*Nitrogen Found (Pounds per Acre).*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | 2,764 | 3,261 | 2,604 | 2,979 | 3,061 | 3,084 |

Nos. 1, 3 and 4 have received no nitrogen except that secured through the clover. Accepting the results obtained by Dr. Frear in 1891, the yard manure used contains .50 per cent. of nitrogen. Hence, there was applied to Nos. 2, 5 and 6 the following amounts of nitrogen in the 16 years of experiment:

*Nitrogen Applied in Fertilizers (Pounds per Acre).*

| | No. 2. | No. 5 | No. 6. |
|---|---|---|---|
| Nitrogen, | 480 lbs. | 576 lbs. | 576 lbs. |

Amount of nitrogen found in excess of that in the unfertilized plot was:

| | No. 2. | No. 5 | No. 6. |
|---|---|---|---|
| Nitrogen, | 497 lbs. | 297 lbs | 330 lbs. |

Loss of nitrogen through crops and leaching:

| | No. 2. | No. 5 | No. 6. |
|---|---|---|---|
| Nitrogen, | *17 lbs. | 279 lbs. | 256 lbs. |

*Gain.

No. 4, which had no nitrogen applied directly, had 215 pounds more nitrogen per acre than the unfertilized plat, indicating that the ground limestone had a beneficial effect on the nitrogen supply. The lime plat contains 160 pounds less nitrogen than the unfertilized plat, which accords with the general opinion that lime without manure ultimately leaves the soil poorer than if the lime had not been applied.

Owing to the fact that soils usually contain most of their nitrogen in organic combination, the proportion present as nitric acid or ammonia being relatively very small, a comparison of the nitrogen with the carbon, and with the *matiere noire*, both the latter being taken as 100, presents some interest.

*Nitrogen Ratios.*

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Ratio to carbon, | 7.49 | 8.10 | 7.88 | 7.96 | 7.93 | 7.90 |
| Ratio to *matiere noir*, | 5.77 | 7.07 | 6.07 | 6.45 | 6.29 | 5.61 |

## CONCLUSIONS.

1. The combustion method affords more satisfactory information concerning the carbonaceous organic matter of the soil, than does the simple process of ignition.

2. Accepting the figures for humus obtained by the application of the Wolff factor to the percentages of organic carbon and the weight of a cubic foot of the soil as represented by that actually determined for a block of soil taken to the depth of seven inches, the first nine inches of soil over an acre would contain the following amounts of humus in tons:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| **Humus,** ........................... | 31.48 | 34.37 | 28.14 | 32.04 | 32.82 | 33.59 |

The gain or loss as compared with the unmanured plats is:

| | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|
| **Humus,** ........................................ | +2.89 | —3.34 | +.56 | +1.34 | +2.11 |

The corresponding amounts of *matiere noire* in tons per acre to a depth of nine inches, are:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| *Matiere noire,* ..................... | 23.59 | 22.80 | 21.25 | 22.92 | 24.19 | 27.25 |

The gain or loss as compared with the unmanured plats is:

| | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|
| *Matiere noire,* ................................ | +.89 | —2.44 | —.77 | +.50 | +3.56 |

From the above, the distinctive effect of lime in the caustic condition, upon the humus is clearly seen, it being much more active than the ground limestone. In either form, lime very perceptibly decreases the *matiere noire.* Of the humus on the plats receiving yard manure and lime, less seems to have been converted to *matiere noire.* The acidity of soil on the sulphate of ammonia plat, indicated by the growth of sorrel, may have preserved the humus of that plat from so rapid destruction.

3. The amount of nitrogen is decreased by a continued use of caustic lime without the addition of other manures, there being 160 pounds less per acre than in the plat receiving no manure. Ground limestone ($CaCO_3$), although not directly supplying any nitrogen, increased the amount in the soil, probably by producing a greater growth of clover and thus increasing the nitrogen through the roots that remain in the soil.

Nitrogen applied to the soil in yard manure was not lost very largely, as there were 497 pounds per acre found above that in the unfertilized plat, while only 480 pounds had been applied during the sixteen years of the experiment. With nitrate of soda only 51.58 per cent. of the nitrogen applied was accounted for by the increase above the unmanured plat, while in the case of sulphate of ammonia 55.55 per cent. of the nitrogen applied remained in the soil. This would indicate that much of the nitrogen leached away, although part of it was taken off in the heavier crops produced.

The ratio of nitrogen to carbon is very uniform under the different fertilizer treatments, it varying from 7.49 per cent. in the unmanured plat to 8.10 per cent. in the plat receiving yard manure and lime.

## NOTES.

BY WILLIAM FREAR.

1. The weight obtained for a cubic foot of the soil seems low for the kind of soil, results of Schübler, Johnson and others pointing to 75 to 80 pounds as the probable weight of a cubic foot taken to the depth of 12 inches. It should be recalled, however, that the depth to which the soil was taken in this case was little more than 6 inches and that the more compact subsoil would naturally weigh more. Assuming a normal weight of 80 pounds per cubic foot taken to the depth of 12 inches, and that the soil sample weighed, correctly represents the upper six inches over the entire field, the weight of the upper 9 inches of soil over the acre would be 1,241 tons, of which 9.75 tons would constitute .786 per cent.

2. The time allotted to the drying of the samples over sulphuric acid was scarcely sufficient to secure the entire removal of hygroscopic moisture. There is no assurance that constant weights were attained as the result of this drying. Van Bemmelen gives 6.2, 4.45, 6.8, 3.7 and 5.0 per cent. as the amounts he found to be lost when several air-dry soils were allowed to come to constant weight over

sulphuric acid. (Ldw. Vers. Stat., 37, 257-278). He gives, however, no statement of the time required for the drying. His samples were much more moist at the outset than the air-dry soils used here. Owing to the uncertainty of completeness of drying in Mr. Hess's results by the Van Bemmelen method, those by the ordinary method are used as the basis for estimation of water-free substance.

3. Van Bemmelen, in recommending this method of determination, assumes (1) that the composition of the entire humus is correctly represented by that part extractible from the soil by the action of solutions of alkaline carbonates or hydrates and precipitated from the extract upon neutralization or weak acidulation; (2) that Wolff's factor, 0.471, applied to the carbon dioxide evolved during combustion from the organic matter, correctly represents the proportion of carbon in the humus materials thus extracted. The first assumption results in only an uncertain approximation to the truth; it is well known that the proportion of carbon in the original undecayed plant residues is more nearly 48 per cent. than 58 and that, during decay the loss of other elements is relatively more rapid than that of carbon—those substances, such as sugars, starch and proteids, that are more readily destructible by ferments and are, at the same time, less highly carbonaceous than the woody and ligneous matters, disappearing first; but at what stage of chemical decomposition the humus may be considered to be formed, is undetermined; since, however, the fine, sifted soils still contain, after extraction with solutions of alkaline carbonates, important quantities of carbonaceous substance, it may be questioned whether the factor is not too low, to to properly represent the total humus of the soil. As for the correctness of the Wolff factor as a representative of the composition of the alkali-extractible organic matters, corresponding to a carbon percentage of 58: The analyses collected by Wollny (Die Zersetzung der Organischen Stoffe und die Humusbildungen, etc., 1897, p. 215), representing numerous samples of four different kinds of natural humus, show a range of 52.14 to 59.74 per cent., mean, 56.05 per cent.; while similar materials artificially prepared from sugar, contained 64.7 per cent. of carbon. Wiley (Analysis, I, 326), states the range of carbon to be from 40 to 72 per cent. Van Bemmelen has found, however, in the hydrogen relations of the soil, a check upon his work, the samples having been thoroughly dried over sulphuric acid prior to analysis. If the humus, calculated from the carbon, be subtracted from the total loss on ignition, the remainder should represent little else than water of hydration, containing, of course, 11.11 per cent. of hydrogen. The total water obtained by combustion in a current of oxygen represents both the water of hydration and that formed from the hydrogen of the humus. Now the analyses of humus collected by Wollny show that the percentage of hydro-

gen in natural humus ranges from 4.4 to 7.03, but approximates 5.6 on the average; cultivated soils tend to a somewhat lower percentage of this constituent. Van Bemmelen has adopted 5 per cent. as the average. The figures he obtained for water, by direct estimation by combustion and by computation from the loss of weight upon ignition and the carbon (humus) determination in a number of analyses are as follows:

*Check Determination: Water by Combustion.*

| | Found. | Calculated. |
|---|---|---|
| Heavy sea clay (recent), | 8.57 | 8.61 |
| Lighter sea clay (recent), | 8.57 | 8.45 |
| Volcanic clay, from Deli, | 14.78 | 14.75 |
| Gray volcanic soil from Deli, | 7.63 | 7.74 |
| Volcanic clay, Java, Gondang, | 8.05 | 8.06 |
| Volcanic clay, Java, Sirka, | 4.70 | 4.90 |
| Heavy alluvial clay, Java, | 6.00 | 6.01 |

These agreements are surprisingly close. It appears that if the organic residues in the soil have had full opportunity for humification and the samples have, prior to combustion, been thoroughly dried over sulphuric acid, quite good results can sometimes be secured by application of Van Bemmelen's method. With the wide range of composition of humus that is known, numerous exceptions to the successful application of this method may, however, be expected.

(4) The discrepancies between the water computed according to Van Bemmelen's method and that found by analysis are too large to be passed without comment. Two explanations suggest themselves: (1) An error in the making of the combustion. The working of the analyst was, however, checked by analyses of pure cane-sugar, with the following results:

| | Found per cent. | Theory per cent. |
|---|---|---|
| Carbon, | 42.06 | 42.11 |
| Hydrogen, | 6.91 | 6.43 |

The presence of a little moisture in the sugar, in part accounts for the slight variation from theory.

(2) A decided difference from the average in the composition of the humus in these soils. Accepting this suggestion, it is found that only some compound relatively richer in oxygen than any specimen of humus known to the writer, would afford a satisfactory agree-

ment between the theory and the actual results of analysis. Thus a material of the composition of apocrenic acid (47.2—50.9 per cent. of carbon, 3.8—4.2 per cent. of hydrogen, and 41.9—47.5 per cent. of oxygen), would much more closely satisfy the conditions of analysis, as the following figures show:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Calculated, | 2.96 | 3.15 | 3.07 | 3.35 | 3.07 | 3.15 |
| Found, | 2.98 | 3.44 | 2.66 | 3.22 | 3.10 | 3.14 |

It is not, of course, intended to imply that apocrenic acid itself is present in such unusual proportions. The real quantity of humus corresponding to the organic carbon in these soils must, therefore, remain indeterminate until further investigations can be made. It may be assumed, however, that the triplication of analytical results warrants the acceptance of the figures for organic carbon in the respective plats.

(6). In addition to the points already discussed in connection with these results, there are a number of others possessing some interest. The hydrogen determinations warrant us in the use of a humus factor at least as large as that suggested by Wolff. Accepting this as a minimum, it is noteworthy that after sixteen years of continuous cropping with a four-course rotation, this clay soil has not fallen below 2.50 per cent. in humus, and so does not belong as yet to the group of "humus poor" soils under Knop's classification. Indeed, the results by the ignition method, upon which his classification is apparently based, warrant the description of the soil as "humus". These results fully illustrate the fact, well known in practice, that clay soils are much less likely to deteriorate in humus during cultivation than are those of a looser texture in which oxidation can more readily take place.

Another point of interest very briefly noted in the thesis, is the relatively small excess of organic matter on the manured plat. In addition to the larger residues of organic matter almost certainly left upon the manured plat by the larger crops it produced, as compared with the unfertilized land, there was added directly in the manure, 9.75 tons of organic matter. Yet at the end of four rotations, an excess over the unfertilized soil of only 2.89 tons is shown. This small amount may be due in part to the action of the lime. If the loss were absolutely the same from this cause on plats 2 and 3, the surplus with which the manure is to be credited is 3.34 tons more, or 6.23 tons. Even with this allowance, there is still a large deficiency in the organic matter added to the soil, to be accounte

In the absence of results from the land treated with yard manure alone, two explanations offer themselves: Either that the organic matter of the manure is more easily oxidizable and therefore less permanent in the soil than is that left by crops—a view which there are many facts tending to support; or the lime acting in the presence of a larger body of organic matter, wrought an absolutely larger result than it did upon plat 3 with less humus.

The action of caustic lime to decrease the humus of the soil is very distinctly shown in these results from field trials, just as it was in the laboratory trials reported in a preceding portion of this report. The annual loss, compared with that of the unfertilized plat, is .21 tons in excess, equivalent to the quantity in one ton of stable manure.

It has been noted in the thesis that the proportion of *matiere noire* to total humus are smaller with the stable manure and lime and the ground limestone treatments than with the remaining courses of fertilizing. The reason for this is not clear; if it were due to some obscure action of lime compounds, the same tendency should be manifest in the results from the application of lime alone. Such tendency does not appear in these results; it is, however, of interest to recall that in the earlier reported laboratory experiments upon the action of lime upon both limestone clay and muck soils, the proportion of *matiere noire* to total humus determined in that case by ignition simply, was strikingly less on the portions limed than those exposed to weathering without any addition.

In the absence of data as to the composition of the soil at the time when the fertilizer experiments were begun, it is impossible to discover whether there has been an absolute loss or gain of humus in any case. It is therefore impossible to draw any satisfactory conclusions respecting the absolute effects of complete fertilizers of mineral composition upon the humus supply of the soil; admittedly, the resultant quantities are less from such fertilizing than where the practice, common in Pennsylvania, of applying liberal dressings of stable manure with lime, was followed; but the differences, in terms of the humus itself, are very small, the nitrate and amomnia treatments producing respectively 95.5 and 97.7 per cent. of the humus produced under the manure and lime treatment. Such differences are far too small to account for the differences in texture of the soil claimed to result elsewhere from the two systems of fertilizing. Differences in other respects than in the humus supply may affect the texture of the soil.

The deficiency of nitrogen on the limed plots corresponds with the results of the laboratory trials already referred to; but the relative gain of nitrogen on the land treated with ground limestone is unexpected and merits further and more detailed study.

# A CONTRIBUTION TO THE CHEMISTRY OF BUTTER-FAT.*

BY C. A. BROWNE, JR.

The results on the chemistry of butter-fat herewith presented constitute partly the work on regular experiments of the Station, and partly extra work performed at odd moments as the other duties of the laboratory permitted.

Nearly all of the analyses were on samples of butter made at the Station creamery, and representing for the most part the product of a herd of high-grade Guernseys. The figures given in the tables accompanying this article need not be taken, therefore, as typical of butter-fats in general, though we believe them to be, on the whole, fairly representative. The differences, if there are any, in the chemical composition of butter-fat from different breeds of cows, is a subject at present being investigated at this station.

We have chosen, for the sake of convenience, to divide our subject into three distinct heads, viz:

1. The physical and chemical constants of butter-fat.
2. The chemical composition of butter-fat.
3. The chemistry of rancidity in butter-fat.

## I. THE PHYSICAL AND CHEMICAL CONSTANTS OF BUTTER-FAT.

A word should be said in regard to the preparation of samples of butter-fat for analysis. The method of procedure adopted in this laboratory is as follows: A sufficient quantity of the butter is placed in a glass jar or beaker and warmed at about 50 degrees C., with occasional agitation, until the water and curd have sep-

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*Read by title before the New York meeting of the American Chemical Society, December 28, 1898, and printed in the Journal, **21**, 612-633; 807-827; and 975-994.

arated out, leaving the layer of butter-fat quite clear. Then, without disturbing any of the water and curd, as much as possible of the melted fat is drawn off with a pipette into another vessel and allowed to stand, if necessary, for further clarification. The sample is then filtered through desiccated filter-paper into a clean, dry jar, after which it is stoppered and preserved for analysis in a cold place away from the light. The special precaution to be noted, in the preparation of the samples, is the avoidance of too high a temperature in melting. Butter-fat is an exceedingly unstable body and a temperature much above 50 degrees C. will very soon produce chemical changes. Too long an exposure at 50 degrees C. even, will alter the composition of butter-fat,* so that no more time than is necessary should be consumed in the processes of melting and filtering.

In Table I are given the results obtained for a few of the common constants usually determined in butter-fat analysis.

*Table I.*†

| Constant. | Range. | Mean. | Number of samples represented. |
|---|---|---|---|
| Specific gravity, $\frac{40°}{15.5°}$, | 0.9050-0.9102 | 0.9073 | 35 |
| Melting-point, | 31.6°-34.6° | 33.2° | 35 |
| Acid number, | 0.20-0.66 | 0.50 | 5 |
| Saponification number, | 224.0-234.9 | 228.5 | 40 |
| Ether number,‡ | 223.5-234.4 | 228 | 40 |
| Iodine number, | 29.36-37.30 | 33.35 | 40 |
| Reichert number (two and a half grams), | 15.10-17.60 | 16.2 | 40 |
| Reichert-Meissl number (five grams), | 22.80-32.10 | 28.3 | 10 |
| Insoluble acids, per cent., | 86.03-88.84 | 87.65 | 10 |

The constants were all determined by the usual processes employed in the analysis of oils and fats; since these are too well known to require any detailed description, we will simply indicate the methods employed, describing only any modifications which are introduced.

The specific gravity was determined on the melted samples at 40 degrees C. by means of a Westphal balance, which gives results accurate to the fourth decimal. Whenever greater accuracy was required a pycnometer or Sprengel tube was used.

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*We have found by experiment that a butter-fat kept at 50° C. for two days suffered a decrease in its iodine number of over one unit.

†The figures from which this and succeeding tables are made up represent the mean of duplicate determinations.

‡Saponification number less 0.5, the mean acid number.

The melting point was determined according to the method of the official chemists.[*]

The acid number, or milligrams of potassium hydroxide necessary to neutralize the free acid in one gram of fat, was determined by heating about ten grams of the fat with fifty cc. of neutral alcohol in a ten-ounce flask provided with a condensing tube. After allowing the alcohol to boil for several minutes, the flask was cooled to about 50 degrees C., when the condensing tube was removed, and the contents titrated with tenth-normal alkali (sodium hydroxide or potassium hydroxide), using phenol-phthalein as indicator.

The determinations of the acid number were made upon samples of fat taken immediately after the butter was churned, so it will be observed that, even when fresh, butter-fat contains an appreciable amount of free acid. This is a fact of some importance upon which we will dwell more fully when treating of the subject of rancidity.

The saponification number, or milligrams of potassium hydroxide necessary to saponify one gram of fat, was determined according to the usual method. About two and a half grams of fat were saponified with exactly twenty-five cc. of half-normal alcoholic potassium hydroxide. To secure concordant results great care must be exercised in measuring of the potassium hydroxide solution; for this reason we prefer a burette to the twenty-five cc. pipette generally recommended. The saponifications were performd in flasks provided with condensing tubes; twenty to thirty minutes were usually allowed for the reaction, after which the contents of the flask were titrated back with half-normal hydrochloric acid, using phenol-phthalein as indicator. Blank experiments were run with every series of determinations.

The ether number, or milligrams of potassium hydroxide necessary to saponify the neutral fat in one gram of sample, is found by subtracting the acid number from the saponification number.

The iodine number, or percentage of iodine absorbed by the fat, was determined according to the method of the official chemists.[†] A burette was used for measuring the iodine solution as more concordant results could be secured than when a pipette was employed.

The volatile acid numbers were determined partly by the Reichert method, when two and a half grams of fat were taken, and partly by the Reichert-Meissl process, when five grams of fat were employed. With the exception of the quantity of fat weighed out the method of procedure was the same in both cases, Wollny's process[‡] for saponification and distillation being the one adopted.

It is a well-known fact that the method of determining the volatile acids in butter-fat by the ordinary process of distillation is not a quantitative one. The number of cubic centimeters of half-normal alkali consumed is always greater by the Reichert process, as a larger percentage of the volatile acids are driven over when working with a smaller quantity of fat; the results in Table I show that the Reichert process gives a mean constant ten per cent. higher than the Reichert-Meissl method, after calculating the figures both to the same weight of fat.

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[*] Bulletin No. 46, Division of Chemistry, U. S. Department of Agriculture, p. 34.
[†] *Ib.* 32.
[‡] Ztschr. anal. Chem. (1889), 28, 721.

Richard Meyer found that by distilling with a current of steam, the number of cubic centimeters of half-normal alkali was increased by twenty-five per cent. The experience in this laboratory has been that only from seventy-five to eighty per cent. of all the volatile acids pass over in one distillation. As a test, ten distillations were made on two and a half grams of fat, the contents of the flask being replaced with 110 cc. of water after each distillation. The first fraction took 15.5 cc. of tenth-normal alkali, the succeeding nine fractions requiring each in their order, 2.00, 0.95, 0.60, 0.55, 0.40, 0.35, 0.30, 0.30, 0.25, or together 5.7 cc., giving a total of 21.2 cc., thus making the original Reichert number of 15.5 over twenty-five per cent. too small.

Instead of distilling the lower fatty acids it is possible to remove them from the higher insoluble acids by washing.* The process can be carried out in connection with the determination of the saponification number, or with the determination of the insoluble acids. If worked in connection with the former the method of procedure is as follows:

Having determined the saponification number of the fat the flask is replaced on the steam-bath until all alcohol is removed. The residue of soap is then dissolved in 100 cc. of hot distilled water, and after cooling to about 60 degrees just enough half-normal hydrochloric acid is added to unite with all the combined alkali.† The flask is then stoppered with a condensing tube and heated on the steam-bath until the fatty acids have risen to the surface and the liquid underneath has become clear. The flask and contents are now thoroughly cooled, after which the cake of insoluble fatty acids is gently detached from the walls of the flask by shaking and the liquid filtered into a liter flask. One hundred cc. of hot water are then poured into the saponification flask and, after the acids have melted, thoroughly shaken. The contens of the ffask are poured on the filter and the flask again washed out with hot water; this is repeated until all the fatty acids are removed from the flask, when they are washed directly on the filter. As soon as the filtrate amounts to a litre it is titrated with half-normal alkali. It is needless to remark that the water used for washing should be absolutely neutral.

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*Allen: Commercial Organic Analysis (1899), Vol. II, Part I, p. 191.

†The amount of half-normal hydrochloric acid necessary for this can be found by subtracting the number of cubic centimeters of half-normal hydrochloric acid used in titrating the excess of potassium hydroxide in the determination of the saponification number from the number of cubic centimeters of half-normal hydrochloric acid used to neutralize the potassium hydroxide in the blank experiment.

Although a larger percentage of the lower acids is generally removed by the above process of washing than by one distillation, the same difficulty of effecting a complete separation of the soluble from the insoluble acids is experienced. It has been found impossible to remove the last traces of soluble acids, even by continued washings, the higher and less soluble homologues, caprylic and capric acids especially, being retained by the insoluble acids on the filter. The first filtrate (one liter) of soluble acids from a butter-fat, treated by the process of washing just described, required 15.5 cc. of tenth-normal alkali. The acids on the filter were washed nine more times, using a liter of hot distilled water at each washing. The succeeding filtrates required each in their order, 1.05 cc., 0.60, 0.50, 0.40, 0.35, 0.35, 0.30, 0.30, 0.15, making in all 19.5 cc. It is evident that, while one treatment is amply sufficient to distinguish a butter from a substitute, the method is of little value quantitatively unless the treatment of washing be repeated until the washings become neutral—a tedious operation at the best.

The process employed by us for determining the percentage of insoluble acids, or Hehner number, is as follows: Ten grams of the fat are weighed out into a wide-necked 250 cc. flask and saponified with five cc. of fifty per cent. soda and twenty-five cc. of ninety-five per cent. alcohol. The alcohol is then distilled off and the residue of soap dissolved in 150 cc. of water; 50 cc. of hydrochloric acid (1:1) are then slowly added with continuous shaking, after which the flask is replaced on the steam-bath and allowed to stand until the liquid beneath the layer of fatty acids has become perfectly clear. The flask and contents are now cooled; the cake of fatty acids, after hardening perfectly, is loosened from the walls of the flask by shaking gently, and the liquid underneath poured through a clean filter. The short arm of a glass siphon is then introduced, allowing the end of the tube to come in contact with the bottom of the flask; the discharging end of the siphon is closed by a piece of gum tubing fitted with a pinch-cock. The flask is now filled about three-fourths full with hot water and thoroughly agitated; after allowing the fatty acids to rise to the surface of the liquid, the siphon is filled by blowing in hot water from a wash-bottle at the lower end, the process being easily controlled by the pinch-cock. In this way also any of the fatty acids, which have risen within the siphon, can be washed back into the flask. The liquid underneath the layer of fatty acids is now siphoned off into the paper used for the first filtration, the pinck-cock serving to regulate the flow. When as much as possible of the liquid is drawn off, without taking any of the insoluble acids, the flask is again nearly filled with hot water and shaken; after washing out the siphon, the liquid is drawn off as before. The process is continued until the washings cease to redden litmus paper; about ten washings, requiring over two liters of water, are generally necessary to effect this. When the washings are neutral the siphon is removed, any acids which may remain adhering to it, being washed back into the flask with hot water; the flask is cooled and as soon as the acids have hardened the cake is detached and the washings poured through the filter. The flask is then placed in an inverted position over the filter and allowed to drain over night. In the morning the filter-paper, which generally contains a small quantity of insoluble acids, is washed several times with a few cubic centimeters of ether, the washings being allowed to run into the flask. The flask is then warmed at 80 degrees until most of the ether is expelled and then dried at 100 degrees to constant weight. We have found it expedient to dissolve out the acids, after securing a constant weight, with hot alcohol and reweigh the flask; a difference of several milligrams is generally experienced between the first and last weighings, due to the removal of soluble matter from the glass.

We believe a quicker and more thorough washing of the insoluble acids, with less danger of loss, is secured by this method than by the usual processes for determining the insoluble acids. Duplicate results can be secured which agree perfectly. The method is applicable not only to the analysis of fats and oils, but we have used it to advantage in soap analysis.

One point which we have observed in connection with the drying of fatty acids to constant weight at 100 degrees C. is that when the acids were dried in a low evaporating dish or beaker a constant weight could never be secured; the acids continued to lose in weight even when it was evident that all moisture was removed; when, on the other hand, the drying was performed in a flask a constant weight was soon secured, after which no change was observed, even on many hours' drying. This difference we believe to be due to a partial volatilization of the insoluble acids; the escape of volatile products would be much easier from an open dish than from a flask; moreover, we have always found, after removing the flask containing the insoluble acids from the oven, that the inner surface and lower parts of the neck of the flask were coated with a thin layer of condensed acids, showing that a volatilization must have occurred.

In Table II are given figures for a few of the constants less frequently determined in the analysis of butter-fat.

*Table II.*

| Constant. | Range. | Mean. | Number of samples represented. |
|---|---|---|---|
| Acetyl number, | 3.5-4.8 | 4.1 | 5 |
| Glycerol calculated,* | 12.24-12.79 | 12.46 | 40 |
| Glycerol by analysis, | 12.30-12.70 | 12.45 | 10 |
| Total fat acids calculated,* | 94.72-94.94 | 94.85 | 40 |
| Soluble fat acids calculated, | 6.52-8.96 | 7.20 | 10 |
| Specific gravity $\frac{20°}{20°}$ of insoluble acids, | 0.9106-0.9242 | 0.9162 | 10 |
| Melting point of insoluble acids, | 40.2°-42.7° | 41.7° | 10 |
| Saponification number of insoluble acids, | 212.5-217.0 | 214.5 | 10 |
| Mean molecular weight of insoluble acids, | 258.1-263.5 | 261.0 | 10 |
| Specific gravity $\frac{20°}{20°}$ of soluble acids, | 0.9475-0.9483 | 0.9479 | 2 |
| Saponification number of soluble acids, | 563.7-577.3 | 571.7 | 15 |
| Mean molecular weight of soluble acids, | 97.17-99.52 | 98.12 | 15 |

The acetyl number, or milligrams of potassium hydroxide necessary to combine with the acetic anhydride in one gram of acetylized fatty acids, was determined according to the method of Benedikt and Ulzer.† The process, as conducted in this laboratory, is as follows: Fifty cc. of the melted fat are saponified, the resulting soap is decomposed with hydrochloric acid, and the insoluble acids secured according to the usual methods. Twenty-five cc. of the dried and filtered acids are boiled with twenty-five cc. of glacial acetic acid, for two hours, in a 250 cc. flask connected with a reflux condenser. The mixture is then poured into a large two-liter flask filled three-fourths full with boiling water; the flask is thoroughly agitated for some minutes and then allowed to stand until the acids have risen to the surface. After cooling perfectly under running water, the cake of acids is gently detached from the walls of the flask and the liquid underneath poured out; the flask is then filled half full with hot water and the contents boiled for half an hour; a few pieces of clean pumice stone, which have been kept under water, are added to prevent bumping. The liquid underneath the acids is then removed by a siphon and the acids washed by siphonation, as under determination of insoluble acids, until the wash-water is neutral. The acids in the flask, after hardening, are allowed to drain; they are then melted, transferred to a smaller vessel, and dried at 100 degrees until all water is removed, after which the acids are filtered through dry paper and preserved for analysis.

To determine the acetyl number, three to five grams of the acetylized acids are weighed out into a 250 cc. flask, dissolved in fifty cc. of neutral alcohol, and titrated with half-normal alcoholic potash, using phenol-phthalein. The milligrams of potassium hydroxide for one gram of acid are calculated as in the determination of the acid number, and the number so obtained is designated the acetyl-acid number. An excess of the alcoholic potassium hydroxide is then added, the flask is stoppered with a condensing tube, and heated on the bath twenty to thirty minutes, after which the excess of potassium hydroxide is titrated back with half-normal hydrochloric acid. The quantity of potassium hydroxide consumed by this second process, when expressed in milligrams per gram of fat, constitutes the acetyl number. The sum of the acetyl-acid number and acetyl number is known as the acetyl-saponification number. The acetyl number then represents simply the ether number of the acetylized acid, being the difference between the acetyl-acid and acetyl-saponification numbers.

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*Calculated from figures given for ether number in Table I.

†Monatsh. Chem., 8, 40; Analyse der Fette, 3rd Ed., p. 146.

In reviewing the literature of the subject only two other values could be found for the acetyl number of butter-fat. Wachtel gives 9.6, and Bondzynski and Rufi 18.2, numbers both considerably higher than the values given in Table II. The acetyl figure, though of little value in practical butter analysis, yet furnishes us a measure of the oxy-acids in a fat; more will be said as to the employment of this constant under the subject of rancidity.

The percentage of glycerol which a butter-fat will yield upon saponification can be readily calculated from the ether number. In the saponification of any triglycerid three molecules of potassium hydroxide separate one molecule of glycerol, or 168.3 parts of potassium hydroxide correspond to ninety-two parts of glycerol; one gram, therefore, of potassium hydroxide would equal 0.5466 gram of glycerol.[*] If E represents the ether number of a fat, the percentage of glycerol, G, which the fat will yield, will be,

$$G = 0.05466\ E.$$[†]

This indirect method of estimating glycerol can be used in the analysis of any fat or oil which belongs to the class of triglycerids: with diglycerids the method is not practicable as Benedikt has shown.[‡] With rancid fats, owing to the presence of aldehyde bodies, as will be shown later, the method gives too high results.

The percentage of glycerol was determined directly by the method of Benedikt and Zsigmondy,[||] which is based upon the fact that one molecule of glycerol, when oxidized in a strongly alkaline solution with permanganate, produces quantitatively exactly one molecule each of oxalic acid and carbon dioxide.

$$C_3H_8O_3 + 3O_2 = C_2H_2O_4 + CO_2 + 3H_2O.$$

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[*] Zulkowski: Ber. d. chem. Ges., **16**, 1140.

[†] Benedikt: Analyse der Fette und Wachsarten, 3rd Ed., p. 182.

[‡] *Ibid.*, p. 182.

[||] Chem. Ztg., **9**, 975. Analyse der Fette, p. 182.

Allen's* modification of the original process of Benedikt and Zsigmondy, was followed in this laboratory with the exception of a few minor differences.

Ten grams of butter-fat are weighed into a six-ounce saponification flask of heavy glass provided with a tightly fitting glass stopper. Five grams of potassium hydroxide dissolved in fifty cc. of water are then added and the glass stopper wired in securely. The flask is placed in the steam bath and shaken thoroughly every fifteen minutes, the heating being continued until the contents of the flask become thick and homogenous, and no more liquid fat is seen swimming on the surface: eight to twelve hours is generally necessary for this. When saponification is complete the flask is cooled, unstoppered, and the contents washed out into a large beaker with 200-300 cc. of hot water. A perfectly clean solution should be obtained without any oily particles being visible.

The solution of soap is decomposed with an excess of dilute sulphuric acid, and the fatty acids separated and washed in the usual way; the washings, which should be clear, are made up to one liter and thoroughly mixed. 200 cc. (two grams of fat) of this solution are measured out into a large evaporating dish or beaker, diluted to about 400 cc. and neutralized with potassium hydroxide solution using phenol-phthalein. Ten grams of solid potassium hydroxide are then added, and when completely dissolved, a saturated solution of permanganate is added, at ordinary temperature, until the liquid is colored no longer green, but a very dark-blue (three to five grams of permanganate are sufficient for this). The solution is then heated to gentle boiling for about an hour, the liquid becoming finally red with precipitation of the hydrated peroxide of manganese; the volume of the liquid, during the boiling, should be kept at about 400 cc. by adding water from time to time. A strong solution of sodium sulphite is then gradually added until all color is destroyed, and the liquid above the brown precipitate is clear. The solution is next filtered through a large funnel, using heavy filter-paper, into a liter flask, and the precipitate washed with hot water until the flask is nearly full; the slight turbidity, which frequently shows in the final washings, does no harm. After cooling and making up to one liter, 500 cc. (one gram original fat) are measured into a large beaker, acidified with acetic acid, heated nearly to boiling, and precipitated with ten cc. of a ten per cent. calcium chloride solution; the liquid is heated on the steam-bath an hour or more until everything has settled out. The precipitate, consisting of calcium oxalate, with a little sulphate mixed, is filtered into a prepared Gooch crucible and thoroughly washed with hot water. The contents of the Gooch crucible, including the asbestos felt, are then washed back into the original beaker with about 200 cc. of hot water, acidified with dilute sulphuric acid, and heated on the bath for ten minutes, after which the solution is titrated with tenth-normal permanaganate. One cc. of tenth-normal permanganate equals 0.0046 gram of glycerol.

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*Allen; Commercial Organic Analysis, 3rd Ed., (1899), Vol. II, Pt. 1, p. 314.

The oxidation method for determining glycerol is a somewhat long and tedious one, requiring also a certain amount of practice to secure good results. The details of the method, as regards the oxidation, must be rigidly adhered to. Benedikt* states that the soluble fatty acids, butyric, etc., which are present in the same solution with the glycerol, do not yield oxalic acid on the treatment with potassium hydroxide and potassium permanganate, but that this is true only so far as regards the original method. Johnstone† and Mangold have both found that in strongly alkaline solutions butyric acid can be oxidized to oxalic acid. Experiments in this laboratory confirm this; if too great an excess of either potassium hydroxide or potassium permanganate is used for oxidation, or if during the process of boiling, the liquid is allowed to become too concentrated, abnormal results are secured. A butter-fat which gave 12.35 per cent. of glycerol, when analyzed according to the method, yielded over eighteen per cent. of glycerol, by employing a large excess of potassium hydroxide and potassium permaganate, and oxidizing in a concentrated solution, thus proving beyond doubt that the soluble acids had been acted upon. By observing the necessary precautions, however, no danger need be apprehended from this source; we have found the method to yield most excellent results on many of the ordinary fats, as well as on butter-fat itself, the agreement between the percentage of glycerol as calculated from the ether number, and as determined by analysis, being very close, as the following examples will show.

| Fat. | Ether number. | Glycerol calculated. Per cent. | Glycerol by analysis. Per cent. |
|---|---|---|---|
| Beef-tallow, | 195.5 | 10.68 | 10.61 |
| Commercial stearin, | 192.3 | 10.51 | 10.56 |
| Butter-fat, | 232.2 | 12.69 | 12.70 |

The total percentage of fatty acids which a butter-fat will yield can be readily calculated if we know the percentage of glycerol produced on saponification.‡ By inspecting the formula,

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*Analyse der Fette, 3rd Ed., p. 184.

†Chem. News, 63, 11.

‡Zulkowski; Ber. d. chem. Ges., 16, 1315,

$$C_3H_5(RO_2)_3+3H_2O=C_3H_8O_3+3RO_2H$$

Fat+water (54)=glycerol (92)+fatty acid,

we observe that in saponifying a fat fifty-four parts of water are required for every ninety-two parts of glycerol produced. The yield of fat acids ($F$) from 100 parts of fat would be represented then by the formula, $F = 100 + \frac{54}{92}\ G - G$, or $F = 100 - \frac{38}{92}\ G$, in which $G$ equals percentage of glycerol. $G$ as we have shown, can be obtained from the ether number ($E$) of a fat by the formula, $G=0.05466\ E$; by substituting this value for $G$ in the previous equation we obtain, $F= 100 - \frac{38}{92} \times 0.05466\ E$ or $F= 100 - 0.02258\ E$.[*]

The percentage of soluble acids in a butter-fat can be found by subtracting the percentage of insoluble acids (Hehner's number) from the percentage of total acids.[†]

The specific gravity of the insoluble acids was determined by weighing the acids in air and in water at 20 degrees, using a sinker. For a sinker we have found a small platinum crucible cover to answer very satisfactorily, since it offers a convenient receptacle for holding the acids; a silk thread is used for suspending the cover from the beam of the balance; no air bubbles should be present on the surface of the sinker during the operation and to prevent their appearance recently boiled distilled water is used throughout the work. The following example will illustrate the method:

Weight of sinker and fatty acids in air = 6.5460 grams

Weight of sinker alone in air = 5.2110 grams

Weight of insoluble fatty acids in air = 1.3350 grams =

Weight of sinker in water at 20 degrees = 4.9715 grams =

Weight of sinker and acids in water at 20 degrees = 4.805 grams = $w$!

From the formula $s = \frac{w}{w + \omega - \omega'}$, we calculate the specific gravity of the insoluble acids to be 0.9106. This formula is sufficiently accurate for ordinary purposes; more strictly it should read, $s = \frac{w\,(1 - \sigma)}{w + \omega - \omega'} + \sigma$, in which $\sigma$ equals the density of air; the value of $\sigma$ for dry air, within the ordinary range of temperature and pressure, is 0.0012. If we desire to express the gravity in terms of wafer at 4 degrees we should use the formula $s = \frac{w\,(d - \sigma)}{w + \omega - \omega'} + \sigma$, where $d$ equals the density of water at the temperature of the experiment, a value easily found from tables. At 20° $d$ is 0.9982; our original specific gravity, then, corrected to $\frac{20^\circ}{4^\circ}$ would be 0.9091 instead of 0.9106.[*]

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[*] Benedikt: Analyse der Fette, 3rd Ed., p. 162.

[†] *Ibid.*, p. 165.

The melting-point of the insoluble acids was determined by observing the temperature at which the acids became transparent when heated in a capillary tube. A small piece of capillary tubing, about one inch in length, is sealed at one end and nearly filled with the melted fatty acids; there should be no air space beneath the fatty acids and to prevent this, the filling of the tube is best accomplished with a small pipette or dropper, the end of which has been drawn out to a slender point. The tubes should be filled and cooled several hours before making the determinations.

In conducting the experiment the small tube containing the fatty acids is fastened to the bulb of a delicate thermometer and then lowered into a large test-tube, nearly full of distilled water recently boiled and cooled; the test-tube is fastened into a tall beaker nearly filled with water. Heat is now gently applied, keeping the water in the outer vessel constantly stirred by means of a blowing bulb. As soon as the temperature of the water in the beaker reaches 38 degrees, the heat is raised more slowly, about 1 degree in five minutes. A difference of about 1 degree is generally observed between the beginning of melting and the point of absolute transparency; we have used the latter as the true melting-point, though the mean of the two readings would be perhaps a little more correct. The method of the official chemists would not be practicable in the case of determining the melting-point of the insoluble acids, owing to the solubility of the acids in alcohol.

The saponification number of the insoluble acids, which in this case would be identical with the acid number, was determined by dissolving three to five grams in hot neutral alcohol and titrating with half-normal potassium hydroxide.

From the saponification number ($s$),[†] the mean molecular weight ($m$) of the insoluble acids can be readily calculated by means of the formula $m = \frac{56100}{s}$.[‡]

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[*] This method can be used as well for determining the specific gravity of butter-fat at the ordinary temperature. We have found the mean specific gravity of butter-fat corrected to $\frac{20^\circ}{4^\circ}$ to be 0.9250.

[†] Analyse der Fette, p. 163.

[‡] In the Chem. Rev. Fett u. Harz-Ind., 5 [9], 169-172, R. Henriques calls attention to a difficulty in estimating the mean molecular weight of the insoluble acids from butter-fat, in that the values found on drying the acids at 105°-110° C. (viz., 267-270) differed from those (256.3-263) obtained when the drying was effected at the ordinary temperature in a vacuum. (Abstract in Analyst, No. 274, p. 7.)

The values found by Henriques on drying in a vacuum are identical with those given by us in Table II. The higher values, found on drying the acids at 105°-110°, we believe to be due to a partial volatilization of acids of low molecular weight, such as lauric and myristic, which, as will be shown in a later article, are present in the insoluble acids of butter-fat in considerable quantity. Such a volatilization may occur at even 100°, as we have already indicated (p. 212).

For the determination of the constants of the soluble acids from butter-fat, it is necessary first to separate the acids in a state of complete purity. To effect this the following process was employed:

One hundred grams of butter-fat were saponified with fifty cc. of fifty per cent. sodium hydroxide solution and 200 cc. of alcohol in a large flask provided with a condensing tube. After distilling off the alcohol, the residue was dissolved in hot water, decomposed with excess of hydrochloric acid (1:1), and heated on the bath using the condensing tube, with occasional shaking until the liquid underneath the layer of acids had become clear. The contents of the flask were then cooled, the cake of acid detached, and the liquid underneath filtered through heavy paper into a large evaporating dish. The insoluble acids were then remelted, brought upon the filter with hot water and washed until the filtrate became neutral. The combined filtrates and washings were neutralized with sodium hydroxide solution using phenol-phthalein and evaporated to about 500 cc.; the solution was next filtered into a large separating funnel, acidified with dilute sulphuric acid, and after cooling shaken with fifty cc. of washed ether. After standing for a few minutes, the two solutions were separated and the aqueous liquid again treated with fifty cc. of ether; the process was repeated for a third time when the combined ethereal solutions were filtered into a dry dish and the ether allowed to evaporate at the room temperature; the residue of soluble acids* (five to six grams) was dried in a vacuum over sulphuric acid and then preserved in a stoppered vial. The soluble acids thus obtained consisted of a light mobile liquid having a pale straw color,† and giving the intense odor characteristic of butyric acid.

The specific gravity of the soluble acids was determined at 20 degrees C. by means of a two cc. pycnometer.

The saponification number was determined by titrating one to two grams of the acids, dissolved in neutral alcohol, with half-normal potassium hydroxide. Knowing the saponification number ($s$) the mean molecular weight of the soluble acids is determined by the formula $m = \frac{56100}{s}$.

We are well aware that the figures given in Table II for the mean molecular weight of the soluble fatty acids are much lower than those given by certain German authorities. Benedikt‡ gives 139 as the mean molecular weight of the volatile fatty acids from butter-fat. This number was not found directly, however, but was calculated on the assumption that the Reichert-Meissl number is a quantitative expression for the amount of volatile acids, an assumption not warranted by experiment as has been shown.[*]

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*A quantitative separation of the soluble acids is not effected by the treatment.

†If distilled in a vacuum the acids can be obtained colorless.

‡Analyse der Fette, 3rd Ed., p. 546.

If the calculation be made on the volatile acid number from ten distillations instead of from one, results will be obtained which approximate very closely those expressed in Table II, as the following example will show. A butter-fat, containing 8.72 per cent. of soluble acids, required to neutralize the volatile acids (ten distillations) from 2.5 grams, 22.3 cc. of tenth-normal sodium hydroxide, or 8.92 cc. of tenth-normal sodium hydroxide per gram of fat. $\frac{8.72}{8.92} \times 100 = 97.7$, the mean molecular weight of the soluble acids. Practically the same figure is arrived at, if we obtain the saturation number of the soluble acids, after their complete removal by washing, according to the method already described.[†] Two and five-tenths grams of a butter-fat, containing seven and seven-tenths per cent. of soluble acids, required 19.5 cc. of tenth-normal sodium hydroxide to neutralize the soluble acids removed by washing. The cubic centimeters per gram of fat would be seven and eight-tenths and the mean molecular weight would equal $\frac{7.7}{7.8} \times 100$ or 98.7.

We have determined the mean molecular weight of the volatile acids in many butter-fats by still another process. The weight of the barium salts of the volatile acids, is determined and, from the amount of barium oxide contained therein, the mean molecular weight of the combined acids is calculated by means of the formula $m = \frac{76.7\,(r - b)}{b} + 9$, in which $m$ is the mean molecular weight sought, $r$ the weight of barium salts, and $b$ the weight of barium oxide. The process can be carried out in connection with the determination of the Reichert or Reichert-Meissl number. After neutralizing the distillate of volatile acids with half-normal barium hydroxide, the solution is evaporated to dryness in a weighted platinum dish, and heated at 100 degrees C. to constant weight. The residue is then moistened with a little strong sulphuric acid, ignited, and weighed; from the weight of barium sulphate is calculated the barium oxide. A comparison of the values obtained for the mean molecular weight of the volatile or soluble acids by the above method and by the method of direct titration is given herewith:

| | Range. | Mean. |
|---|---|---|
| By direct titration, | 97.94-99.51 | 98.73 |
| By weighing the barium salts, | 97.17-98.97 | 97.92 |

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[*] This article, p. 210. Benedikt, elsewhere in his own work, calls attention to this same fact. Analyse der Fette, 3rd Ed., p. 137.

[†] This article, p. 211.

We can verify this figure for the mean molecular weight of the volatile or soluble fatty acids in the following manner:

For the average butter-fat we may consider the following constants to be nearly correct:

| | | |
|---|---|---|
| Saponification number, ........................ | 228.5 | (Table I) |
| Insoluble acids, per cent., ..................... | 87.65 | (Table I) |
| Soluble acids, per cent., ........................ | 7.20 | (Table II) |
| Saponification number of insoluble acids, ....... | 214.5 | (Table II) |

There are required then for the average butter-fat:

228.5 mg. KOH to saponify 1 gram of fat.
$0.8765 \times 214.5 =$ 188.0 mg. KOH to saponify insoluble acids in 1 gram fat.
Difference 40.5 mg. KOH to saponify soluble acids in 1 gram fat.

or 40.5 mgs. of KOH are required to saponify 0.0720 gram of soluble acids. Therefore $\frac{40.5}{0.072} = 562.5$, theoretical saponification number of soluble acids, and $\frac{56100}{562.5} = 99.73$, theoretical molecular weight of the soluble acids in the average butter-fat. While this theoretical figure is a trifle higher than any we have found in actual work, the agreement is sufficiently close to enable us to say that the mean molecular weight of the soluble acids from butter-fat lies very near to the value expressed in Table II.

We have often found it convenient in our work, where an accurate determination was impossible, either from want of time, or lack of material, to make a rough approximation of the percentage of soluble acids; for this purpose we have devised a very simple formula, the only factor necessary to know being the saponification number of the butter-fat. The equation, in which $v$ equals per cent. of soluble acids and $s$ the saponification number, is:

$$v = 0.0018 \left[ s - \left( 188.5 + \frac{228 - s}{2} \right) \right] \times 100, \text{ or } v = 0.09\,(3s - 605).$$

The formula is deduced from data given in the preceding tables. The average butter-fat, having a saponification number of 228, and containing 87.65 per cent. of insoluble acids with a saponification number of 215, would require 188.5 milligrams of potassium hydroxide to neutralize the insoluble acids from one gram of fat. For any butter-fat, having a saponification number $s$, this value was found to be about $188.5 + \frac{228 - s}{2}$. From the molecular weight of the volatile or soluble acids, we find that one milligram of potassium hydroxide neutralizes 0.0018 gram of soluble acids; the difference, therefore, between the saponification number of the butter-fat and the milligrams of potassium hydroxide required for the insoluble acids, multiplied by 0.0018, gives the weight of soluble acids per gram of fat; multiplying this by 100 we arrive at the percentage of soluble acids sought.

The formula is not expected to give results absolutely accurate in any case, since variations in the saponification number of a butter-fat are caused to a considerable extent by differences in the molecular weight of the insoluble acids, differences which the formula, as given, does not take into account.

### THE RELATION BETWEEN THE CONSTANTS OF DIFFERENT BUTTER-FATS.

It was observed, in tabulating the results from many analyses of butter-fat, that there existed a certain ratio between some of the different constants. An inspection of the following table will illustrate this point.

*Table III.*

| Butter-fat. | Saponification number. | Reichert number. | Iodine number. | Melting-point | Specific gravity $\frac{40^\circ C.}{15.5^\circ C.}$ |
|---|---|---|---|---|---|
| 1, ........................................ | 226.1 | 15.3 | 34.85 | 33.5° | 0.9092 |
| 2, ........................................ | 226.3 | 15.6 | 34.58 | 34.5° | 0.9058 |
| 3, ........................................ | 226.9 | 15.7 | 35.45 | 33.8° | 0.9070 |
| 4. ........................................ | 230.9 | 16.1 | 33.67 | 32.5° | 0.9058 |
| 5, ........................................ | 232.7 | 16.2 | 30.96 | 33.0° | 0.9085 |
| 6, ........................................ | 232.9 | 16.3 | 29.56 | 32.4° | 0.9068 |

We notice that with an increase of the saponification number a quite uniform increase of the Reichert number takes place, while the iodine absorption decreases; these are such variations as one would expect; a higher percentage of oleic acid of low combining power would raise the iodine number and tend to diminish the saponification value; similarly an increase in the percentage of the soluble acids of high combining power would elevate both the Reichert and the saponification numbers.

Table IV comprises a few of a large number of butter-fats analyzed at this station by Mr. W. S. Sweetser in 1894, and illustrates this relation even more pointedly than Table III.

*Table IV.*

| Butter-fat. | Saponification number. | Iodine number. | Reichert number. |
|---|---|---|---|
| 1, | 218.8 | 41.32 | 17.1 |
| 2, | 222.4 | 37.30 | 17.5 |
| 3, | 224.6 | 37.00 | 18.6 |
| 4, | 232.5 | 30.21 | 19.4 |
| 5, | 236.2 | 27.17 | 20.8 |
| 6, | 241.5 | 25.91 | 21.3 |

From these tables it would seem as if the percentages of oleic and of the soluble acids in different butter-fats bore a ratio somewhat complementary to one another. It must be remembered that the relations, which the foregoing tables represent, are only general, and by no means fixed; there are butter-fats which show constants bearing relations different from those expressed above, and from isolated cases a table might be constructed showing exactly opposite tendencies. As regards specific gravity and melting-point, no definite relation could be discovered, though the latter showed a tendency to diminish as the saponification and Reichert numbers increased.

## ABNORMAL BUTTER-FATS.

Different observers have reported from time to time cases in which butter-fats showed chemical and physical constants of such abnormality that, were the samples not known to be genuine, an analysis would condemn them at once as spurious.

F. W. Morse* has reported two butter-fats, from individual cows, giving Reichert-Meissl numbers of 16.5 and 11.2. "The samples were very hard, pale in color, and had an odor resembling that of tallow;" these abnormalities and the phenomenally low figures for volatile acids were attributed to an advanced period of lactation, and the presence of cottonseed products in the feed.

Samples 1 and 6 of Table IV are what might be classified as abnormal, though no note was made at the time of analysis as to any peculiarities in physical appearance. The saponification number of Sample 1 is far below the limit usually assigned to this constant, while the iodine absorption is excessively high; the irregularities of these two figures are explained by the prevalence of gluten feed in the ration.

The saponification and iodine numbers of Sample 6 vary at the opposite extreme; root crops, such as sugar-beets and mangels, predominated in the rations fed to the animals producing this butter, and no doubt account for the unusual figures.

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*New Hampshire Experiment Station Report (1893), p. 152.

While the butter-fat from the milk of single cows may frequently show abnormalities, such instances are less common with a full herd, since individual differences would be concealed in a general average; nevertheless, such instances do occur. Farnsteiner* and Karsch report the following constants of two butter-fats:

| | Saponification number. | Iodine number | Reichert-Meissl number. |
|---|---|---|---|
| I. From 180 cows, | 218.53 | 49.57 | 22.80 |
| II. From 25 cows, | 219.74 | 40.00 | 22.11 |

The abnormal chemical constants of these samples were attributed to a very advanced period of lactation; no mention was made as to any anomalies of taste, odor, etc.

Sickness, peculiarities of feed, and advancement in the period of lactation are the principal causes of irregularities in the composition of butter-fat. The subject is one of special interest and illustrates the difficulty, occasionally experienced, of absolutely identifying the character of a questionable butter-fat. It will be of interest in this connection to compare the generally accepted limits for the three constants, used most universally in butter-fat analysis, with the extreme limits, where the names of the observers are bracketed.

| | General limits. | Extreme limits. |
|---|---|---|
| Reichert-Meissl number, | 20-33 | 11.2 (Morse)-41 (Nilson). |
| Saponification number,.. | 220-236 | 216 (Samelson)-245 (Fischer). |
| Iodine number,........... | 26-38 | 19.5 (Moore)-49.57 (Farnsteiner and Karsch). |

## Influence of Ration upon the Chemical Composition of Butter-Fat.†

Allusion has already been made to the influence of certain feeds upon the chemical constants of butter-fat. Considerable work has been performed at the Pennsylvania Experiment Station along this line, in connection with various dairy-feeding experiments, according to plans of Dr. William Frear; the results of this work have, for the most part, not yet been published. A full discussion and tabulation of these experiments would be foreign to the nature and purposes of the present article, but certain general conclusions from the work may be briefly stated in this connection. The work of others has, in the main, been corroborated; this is true especially as regards the effect of different rations upon the volatile acid figure and iodine absorption. It is to be regretted that so few experimenters, in their work along this line, have reported determinations of the saponification number,—a constant, the value of which in butter-fat analysis, as it seems of late, has been too greatly under-estimated.

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*Ztschr. Untersuch. der Nahrungs u. Genussmittel (1898), 16-21; Abstract in Analyst, No. 269, p. 28.

†Bulletins 13 and 16, New Hampshire Experiment Station, contain some excellent experiments along this line. For a full discussion of the subject see article by William Frear in Agricultural Science, 7, No. 3, p. 120

Briefly, the experiments conducted here indicate that, while the tendency of certain feeds, of which gluten meal is a type, is to greatly diminish the saponification number and increase the iodine absorption, other rations, such as those consisting of root products, beets, mangels, etc., have precisely an opposite effect; the extreme figures of Table IV, in butter-fats Nos. 1 and 6 were mostly, if not entirely, produced by just such a difference in ration.

It was found that other feeds, such as cottonseed, linseed, and corn-meal, all produced decided effects upon the chemical qualities of butter-fat; the three feeds named, when fed in moderate quantities, showed a tendency to elevate the saponification number, but there was a difference in other respects; while cotton and linseed meal diminished the Reichert number, corn-meal seemed to increase this constant; cottonseed and corn-meal both caused a marked decrease in the iodine absorption, whereas linseed meal produced an elevation in the iodine figure. Great care must be exercised in the interpretation of results from such experiments; other factors, such as the individuality of the cow and the stage of lactation, must not be lost sight of. The precise influence of a particular food upon the composition of the butter-fat cannot, in every instance, be foretold; we may say that the effect will always be more or less a variable quantity, since a great deal depends upon the nature of preceding rations.*

There is room for much study along this particular line, and further researches are greatly to be desired, not only as regards the effect of different kinds of food upon the chemical qualities of butter-fat, but also as regards that principle of the ration which is most active in producing a given change, as to whether it be of a carbohydrate, an albuminoid, or a fatty nature. The solution of the difficult physiological problem, dealing with the origin and formation of the fat secreted by the lacteal glands, will certainly be promoted by such investigations.

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*Linseed meal, for example, if fed after a cotton meal ration, would elevate the iodine absorption, whereas, if fed after gluten meal, the iodine number would be diminished.

## II. THE CHEMICAL COMPOSITION OF BUTTER-FAT.

We have already spoken, in a somewhat general way, of those proximate components into which butter-fat is resolved by the process of saponification. The percentage of glycerol formed by the breaking up of the glycerides and the methods for its estimation were considered in the previous part. We will confine ourselves, therefore, in the present part to a study of the various fatty acids, both soluble and insoluble, as we obtain them from butter-fat, regarding also, to some extent, the combinations of these different acids with the glycerol base to form what we know as the glycerides, the mixture of which in varying proportions constitutes butter-fat itself.

There is no problem in analytical chemistry more difficult than that of making a quantitative separation of a mixture of different fatty acids. A mixture of two fatty acids is very hard to analyze, much more so a mixture such as we find in butter-fat where at least ten different acids are present. In a case of this kind the most that we can hope for is an approximation, since an exact quantitative separation is impossible in the present condition of analytical chemistry.

Bearing this in mind, it need not be thought strange that the analysis of the fatty acids from butter should be a subject upon which scarcely two writers agree. Chemists are generally quite concordant in determinations of the saponification number and other common constants pertaining to butter-fat analysis; it seems only reasonable, therefore, to attribute such discrepancies as we find in the percentages of the various acids to defective methods of analysis.

In the following table are given the percentages of the different acids in butter-fat according to several authorities:

*Table V.*

| Acid. | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| | Molt.* | Koefoed.† | Bell.‡ | Blyth.§ |
| Oleic, | 26.52 | 31.11 | 36.1 | 40.40 |
| Stearic, | 40.93 | 1.83 | 49.46 | |
| Palmitic, | 20.00 | 25.62 | | 47.50 |
| Myristic, | .......... | 20.13 | | |
| Lauric, | .......... | 7.32 | .......... | .......... |
| Capric, | 7.40 | 1.83 | 2.09 | |
| Caprylic, | | 0.46 | | 0.80 |
| Caproic, | | 1.83 | | |
| Butyric, | | 1.37 | 6.13 | 3.49 |
| Total, | 94.85 | 91.50 | 93.78 | 94.59 |

A difference in the composition of butter-fat itself no doubt explains to some extent the variations in the foregoing table; a difference in composition, however, would hardly warrant such wide discrepancies as we observe between columns 1 and 2 in the case of stearic acid, or between columns 2 and 3 in the case of butyric acid.

A partial separation of the acids of butter into two fractions, one soluble in water and the other insoluble, is very easily effected, as has been shown;|| the real difficulties of the work may be said to begin only with the final analysis of these two portions.

To remove as far as possible the difficulties attending the presence of oleic acid, a butter-fat was selected which gave a rather low iodine absorption; the fat was examined first according to the ordinary methods of analysis and gave the following constants:

| | |
|---|---|
| Saponification number, | 232.7 |
| Ether number, | 232.5 |
| Iodine number, | 29.28 |
| Insoluble acids, per cent., | 86.40 |
| Soluble acids, per cent., | 8.35 |
| Saponification number of insoluble acids, | 215.5 |
| Molecular weight of insoluble acids, | 260.3 |
| Saponification number of soluble acids, | 572.5 |
| Molecular weight of soluble acids, | 98.0 |

One hundred grams of the butter-fat were taken and the soluble and insoluble acids obtained by methods already described. It is

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*Konig: Nahrungs-u. Genussmittel, second edition, p. 281. Original results expressed as glycerides were calculated to fatty acids.

†Koefoed: Bulletin de l' Academie Royale Danoise, 1891; Abstract in Analyst, No. 195, p. 130.

‡Bell: Analysis and Adulteration of Foods, Vol. II, 48. The fatty acids soluble in water were regarded as butyric acid; the 2.09 per cent. of residual acids were soluble in hot water and had a combining weight of 136.

§Blyth: Foods; Their Composition and Analysis, fourth edition, p. 340.

||*Cf.* p. 219.

an interesting and well-known fact that in the natural fats only acids exist that have an even number of carbon atoms.* Besides the acids mentioned in Table V there have been found in butter-fat oxy-acids† and also acetic and arachidic acids;‡ the two latter, however, occur in such minute quantities that their presence is not worth considering.

## ANALYSIS OF THE INSOLUBLE ACIDS.

The two methods most generally followed by chemists for effecting a separation of a mixture of insoluble acids are that of fractional distillation and that of fractional precipitation. In our work the latter method was selected, since it seemed to offer fewer difficulties and fewer sources of error; we have never given the distillation method a fair trial, but a few experiments seemed to indicate that there was an insufficient range in the character of the different fractions and that the whole process was attended with danger of decomposition.||

In making the fractional precipitations the method of Heintz§ was for the most part followed.

The insoluble acids (86.4 grams), obtained from 100 grams of butter-fat were dissolved in ninety-five per cent. alcohol, using such a quantity that nothing crystallized at 25 degrees C. The solution was then cooled to zero, and after several hours, when crystallization was complete, filtered through a funnel kept cold by means of an ice-jacket. The precipitate of fatty acids, consisting of a white crystalline mass, we will designate as Portion I, and the acids contained in the filtrate as Portion II.

Portion I contained, besides other acids, a small quantity of oleic acid held back mechanically; to remove as much as possible of this, the precipitate of acids was dissolved in a small quantity of hot alcohol, recrystallized in the cold, and filtered as before, the filtrate being added to Portion II.

Portion I was again dissolved in about 500 cc. of hot alcohol, cooled in ice-water, and after recrystallization filtered through the ice-funnel; the precipitate constituted Part 1. The filtrate from Part 1 was evaporated to about 300 cc., cooled in ice-water, and the fat acid crystals filtered off as before; the precipitate constituted Part 2. The filtrate from Part 2 was evaporated to about 150 cc., and the process continued for one more crystallization, Part 3 being obtained; the filtrate from Part 3 was added to Portion II.

The different Parts 1, 2 and 3, of Portion I were then washed with

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*Richter's Organic Chemistry, Smith's translation of fourth German edition, p. 186.

†Bondzynski and Rufi: Ztschr. anal. Chem. (1891), 1.

‡Benedikt: Analyse der Fette, third edition, p. 544.

||Koefoed (*Vid. op. cit.* p. 227), however, seems to have used the distillation method with some degree of success.

§Heintz: J. prakt. Chem., **66**, 1.

ether into weighed beakers; after evaporating the ether the acids were dried for a short time at 100 degrees, after which they were cooled, weighed, and preserved for further examination.

Portion II was treated with 100 cc. of a five per cent. solution of magnesium acetate in alcohol, cooled to 0° C., and after crystallization of the magnesium salts was complete, filtered. The precipitate, Part *a*, was washed with 100 cc. of the alcoholic magnesium acetate and the washings added to the original filtrate. The filtrate from Part *a* was then rendered alkaline with ammonia and subjected to a second crystallization at 0° C., when a second precipitate, Part *b*, was obtained; this was filtered off and washed similarly to Part *a*. Nothing more separating from the filtrate at zero, the solution was treated again with ammonia until strongly alkaline; 100 cc. more of the magnesium solution were added and the liquid allowed to stand in the cold for twenty-four hours. The precipitate thus obtained was collected on a filter and washed with small amounts of the alcoholic magnesium solution; it constituted Part *c*.

The three fractions of Portion II, Parts *a*, *b*, and *c*, consisting of the magnesium soaps, were then decomposed with dilute hydrochloric acid, and the liberated acids thoroughly washed with hot water to remove all traces of magnesium. The fatty acids from each fraction were then washed with ether into weighed beakers, and after evaporation of the ether, dried for a short time at 100 degrees, when they were cooled, weighed, and preserved for further examination.

In the analysis of the different fractions from Portions I and II, the saponification number and iodine absorption were determined; from the former constant the mean molecular weight of the mixture of fatty acids is calculated* and from the latter the amount of oleic acid in each fraction is determined;† the oleic acid, though sometimes present in but minute quantities, must, nevertheless, be considered in the analysis of the several fractions.

Some uncertainty prevails as to the accuracy of calculating the percentage of oleic acid in a mixture of glycerides or fatty acids from the iodine number alone. There is not only the possibility of other unsaturated acids existing besides oleic acid, but also the danger that iodine may be substituted as well as added in the course of the reaction. These objections are no doubt valid in the case of many vegetable and fish oils, but apply with less force to the common fats of animal origin, which contain, so far as known, only one unsaturated acid, viz, oleic.

The possibility of iodine being substituted, with the glycerides or acids of butter-fat at least, appears to us to be very slight; after removing the olein or oleic acid by repeated crystallizations of the fat or fatty acids, the percentage of iodine absorbed can be reduced practically to nothing, thus showing that with the higher saturated glycerides and acids but very little, if any, substitution occurs.

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*By the formula $M=\frac{56100}{S}$. Benedikt: Analyse der Fette, third edition, p. 163.

†By the formula $O=\frac{100}{90.07}I=1.1102\ I$, 90.07 being the theoretical iodine absorption of pure oleic acid. Benedikt: *Ibid.*, p. 173.

We have selected as the first step in the calculations the determination of the mean molecular weight of the fatty acids in each fraction after deducting the oleic acid. This result is obtained by the following formula:

$$\frac{100}{m} - \frac{O}{282} = \frac{100-O}{x};$$

or

$$x = \frac{282\,m\,(100-O)}{28200-m\,O}.$$

$O$ = percentage of oleic acid as calculated from iodine number.

$m$ = mean molecular weight of original acids.

$x$ = mean molecular weight after deducting oleic.

If we now assume that there are not more than two acids present in each fraction besides the oleic and that these acids are adjacent homologues of even carbon atoms, then the relative percentage of each acid can be determined from the following formulas:

$$x + y = 100;$$

$$\frac{x}{m_1} + \frac{y}{m_2} = \frac{100}{m}.$$

from which

$$x = \frac{100\,m_1\,(m-m_2)}{m\,(m_1-m_2)};$$

$$y = \frac{100\,m_2\,(m_1-m)}{m\,(m_1-m_2)}.$$

$m$ = mean molecular weight of the two acids.

$m_1$ and $x$ = molecular weight and percentage, respectively of the higher acid.

$m_2$ and $y$ = molecular weight and percentage, respectively, of the lower acid.

The expression $m_1-m_2$ for the saturated fatty acids of even carbon atoms equals 28; substituting this value in the previous equations:

$$x = \frac{100\,m_1\,(m-m_2)}{28\,m};$$

$$y = \frac{100 m_2 (m_1 - m)^*}{28\, m}.$$

To ascertain what acids are present in any particular fraction, it is only necessary to observe between what two homologues the mean molecular weight of the fraction falls, after deducting the oleic.

The formulas, as derived from the two preceding general equations, for calculating the percentage of stearic acid ($S$) and palmitic acid ($P$) in a mixture of the two, knowing the mean molecular weight ($m$), are as follows:

$$S = \frac{28400\ (m - 256)}{28\, m};$$

$$P = \frac{25600\ (284 - m)}{28\, m}.$$

In the same way for palmitic acid ($P$) and myristic acid ($M$):

$$P = \frac{25600\ (m - 228)}{28\, m};$$

$$M = \frac{22800\ (256 - m)}{28\, m}.$$

The analytical data of the various fractions belonging to Portions I and II, together with the calculated amounts of the different acids, are given in the following table:

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*There is some difference among chemists as to the proper formula to use for calculating the percentage of two acids from the mean molecular weight. Benedikt, Hehner, and the majority of German chemists take the formula $\frac{x}{m_1} + \frac{y}{m_2} - \frac{100}{m}$, while the calculations of Allen, Prescott, and many others are based upon the formula $xm_1 + ym_2 = 100\, m$. The former formula seems to us the only correct one. To take for example a simple case:

| | Per cent. |
|---|---|
| 1 molecule stearic acid weighs ........................................ | 284 = 52.59 |
| 1 molecule palmitic acid weighs ........................................ | 256 = 47.41 |
| 2 molecules of mixture weigh, ........................................ | 540 = 100.00 |
| Mean molecular weight of mixture .................................. | $= \frac{540}{2}$ or 270. |

If we determine now from the two formulas, what percentages of stearic and palmitic acids will give a mean molecular weight of 270, we obtain 52.59 per cent. stearic and 47.41 per cent. palmitic, the theoretical results, by the formula $\frac{x}{m_1} + \frac{y}{m_2} - \frac{100}{m}$; whereas the formula $xm_1 + ym_2 = 100\, m$ gives exactly fifty per cent. of each.

## *Table VI.*

| | Portion I. | | | Portion II. | | | Total per cent. |
|---|---|---|---|---|---|---|---|
| | Part 1. | Part 2. | Part 3. | Part *a*. | Part *b*. | Part *c*. | |
| Weight of fraction, | 5.20 grams | 6.01 grams | 21.13 grams | 9.22 grams | 7.82 grams | 5.05 grams | ........ |
| Mean molecular weight of fraction, | 272.2 | 260.0 | 260.7 | 254.6 | 254.5 | 251.2 | ........ |
| Iodine number of fraction, | 3.44 | 10.94 | 15.03 | 8.41 | 19.85 | 25.12 | ........ |
| Per cent. oleic acid in fraction, | 3.82 | 12.14 | 16.68 | 9.34 | 22.03 | 27.88 | ........ |
| Mean molecular weight after deducting oleic acid, | 271.8 | 257.2 | 256.8 | 252.1 | 247.7 | 241.0 | ........ |
| Weight of stearic acid, | *2.95 grams | 0.25 gram | 0.56 gram | ........ | ........ | ........ | 3.76 |
| Weight of palmitic acid, | 2.05 grams | 5.08 grams | 17.05 grams | 7.32 grams | 4.44 grams | 1.79 grams | 37.68 |
| Weight of myristic acid, | ........ | ........ | ........ | 1.05 grams | 1.66 grams | 1.85 grams | 4.56 |
| Undetermined, | ........ | ........ | ........ | ........ | ........ | ........ | †7.90 |

*Contains also the oxy-acids, a correction for which will be introduced later.

†Found by subtracting the sum of the acids determined and the oleic acid 32.50 per cent. (calculated from iodine absorption) from 86.40, the total per cent. of insoluble acids.

The 7.90 per cent. of undetermined acids, which escaped precipitation, includes all of the lauric acid and no doubt a considerable part of the myristic; the percentage of each of these acids can be arrived at in another way. Having five members present in a mixture of fatty acids and knowing the molecular weight and percentage of three of them, the mean molecular weight of the other two can be determined by the following formula:

$$\frac{a}{m_1} + \frac{b}{m_2} + \frac{c}{m_3} + \frac{100-(a+b+c)}{x} = \frac{100}{m}.$$

$a$, $b$, and $c$ are the percentages of the three known acids and $m_1$, $m_2$, and $m_3$ their respective molecular weights. $m$ is the mean molecular weight of the whole mixture and $x$ the mean molecular weight of the two acids sought.

Applying this formula to the case in hand we have for the three known acids, oleic, stearic, and palmitic, the following percentages:

*Table VII.*

| | In 100 parts of butter-fat. | In 100 parts of acids. |
|---|---|---|
| Oleic acid (from iodine number), | 32.50 | 37.61 |
| Stearic acid, | 3.76 | 4.35 |
| Palmitic, acid, | 37.68 | 43.61 |
| Myristic and lauric acids, | 12.46 | 14.43 |
| Total, | 86.40 | 100.00 |

The mean molecular weight of the insoluble fatty acids from the butter was 260.3; substituting these values in the formula we obtain the following equation:

$$\frac{37.61}{282} + \frac{4.35}{284} + \frac{43.61}{256} + \frac{14.43}{x} = \frac{100}{260.3};\ *$$

or $$0.13339 + 0.01532 + 0.17035 + \frac{14.43}{x} = 0.38418;$$

or $$\frac{14.43}{x} = 0.06512;$$

whence $$x = 221.6.$$

This figure for the mean molecular weight falling between 200 and 228 would indicate a mixture of lauric and myristic acids. Knowing the mean molecular weight ($m$) of a mixture of myristic ($M$) and lauric ($L$) acids, the percentages of each may be calculated from the formulas

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*Strictly the formula should also take into account the oxy-acids; this, however, would make no difference with the final results, inasmuch as the mean molecular weight of the determined acids (and hence of the undetermined) would remain the same in either case.

$$M = \frac{22800\ (m-200)}{28\ m};$$

$$L = \frac{20000\ (228-m)}{28\ m}.$$

Substituting the value 221.6 for $m$ in the preceding equations we obtain 79.37 per cent. myristic and 20.63 per cent. lauric acid; this would give in the 12.46 parts of undetermined acids 9.89 parts of myristic and 2.57 parts of lauric acid for 100 parts of butter-fat.

Such a method for analyzing a mixture of fatty acids as the one described manifestly presents many crudities; the method of Heintz, however, "supplies the only means of obtaining an insight into a mixture of non-volatile acids."* Unfortunately, "there is no practical method of proving that two and only two acids are present"* in any particular fraction, and therein lies the principal fault of the method. Allen observes that "as a rule if the mixed fatty acids be divided into a sufficient number of fractions, each fraction will contain only two homologues,"† and this assumption seems to be a fairly reasonable one.

The oleic acid is a disturbing factor throughout the whole process and its presence must be taken into account in the analysis of the different fractions. We believe too little attention has been paid to this point. The method could be improved greatly if there were some good means of removing the oleic acid at the beginning of the process. The plan of converting the mixture of acids into the lead soaps and removing the lead oleate with ether would not work well on a large quantity of acids, and besides this the process does not effect a perfect separation.

We have taken no account thus far of the oxy-fat acids: that such acids are present in butter-fat seems certain from the acetyl figure which the insoluble acids always give. The oxy-acids probably do not exist in the fat as it is secreted from the lacteal glands, but are later oxidation products of the oleic acid—dioxystearic‡ acid being no doubt principally formed.

$$\underset{\text{Oleic acid}}{C_{18}H_{34}O_2} + O + H_2O = \underset{\text{Dioxystearic acid.}}{C_{18}H_{34}O_2(OH)_2.}$$

Owing to the low solubility of the higher oxy-acids in cold alcohol, any oxy-acids present would come down with the first crystallization (Part 1, Table VI), and this fact would alter somewhat the percentages of the acids in this fraction.

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*Hehner and Mitchell: Analyst, No. 249, p. 317.

†Commercial Organic Analysis, third edition, Vol. II, Part I, p. 242.

‡A Scala (Staz. sperim. agri. ital. (1897), p. 613, shows that this acid is formed among the oxidation products of oleic acid.

Benedikt has devised a formula by means of which the percentage of an oxy-acid in a mixture of fatty acids can be calculated from the acetyl number, provided that the constitution and molecular weight of the oxy-acid is known. The equation is

$$x = \frac{100\,c\,m}{a(56100-42c)},^{*}$$

in which $c$ = the acetyl number.

$a$ = the number of hydrogen atoms in the oxy-acid replacable by acetyl.

$x$ = percentage sought of the oxy-acid having a molecular weight $m$.

Applying this formula to the insoluble acids from the average butter-fat having an acetyl number of 4.1 we would obtain for dioxystearic† acid 1.16 per cent., or calculated to the original butter-fat 1.00 per cent. of oxy-acid.

There are no doubt other oxy-acids present besides the dioxystearic acid in the mixture of insoluble acids, so that the results from this method of calculation can be considered only approximate. The percentage of oxy-acids in butter-fat increases with time and is therefore never a fixed quantity. The gradual increase in the acetyl number, together with the decrease in the saponification number of the insoluble acids, with the age of a butter-fat, goes to show that oxy-acids of a high molecular weight are continually being formed. This fact will be explained more fully under the subject of "Rancidity in Butter-fat."

If we introduce a correction for the percentage of oxy-acid, as found, in the first fraction of the insoluble acids and recalculate the stearic and palmitic acids, the analysis of Part 1 would then be:

| | Grams. |
|---|---|
| Dioxystearic acid, | 1.00 |
| Stearic acid, | 1.02 |
| Palmitic acid, | 2.98 |

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*Benedikt: Monatsh. Chem. (1890), 95, and Analyse der Fette, third edition, p. 178.

†For dioxystearic acid in the formula $a = 2$ and $m = 316$.

The complete analysis of the insoluble acids from 100 parts of butter-fat accordingly would be:

| | Grams. |
|---|---|
| Dioxystearic acid, | 1.00 |
| Oleic acid, | 32.50 |
| Stearic acid, | 1.83 |
| Palmitic acid, | 38.61 |
| Myristic acid, | 9.89 |
| Lauric acid, | 2.57 |
| Total, | 86.40 |

A noteworthy fact in connection with the above results is the low percentage of stearic acid in butter-fat. This is somewhat contradictory to the statements which we find given by many authorities on the subject who regard stearic as one of the principal acids in butter-fat, it being placed by some writers as high even as forty per cent. We believe that these statements should be modified somewhat; when we consider that oleic acid of molecular weight 282 constitutes over one-third of the insoluble acids from butter-fat, it is self-evident that the percentage of stearic acid of molecular weight 284 must be small in comparison with that of its lower homologues, to give a mean molecular weight of 261 to the whole mixture.

Koefoed,* in his analysis of butter-fat, obtained only 1.83 per cent. stearic acid which, by a strange coincidence, is exactly the same quantity found by us after correcting for the oxy-acids.

Hehner † and Mitchell, by removing the oleic and lower insoluble acids with dilute alcohol and analyzing the residue, obtained only from one and three-tenths to three and six-tenths per cent. stearic acid; the same authorities, with their process‡ of removing all other acids by treatment of the insoluble acids at 0° C. with a saturated solution of stearic acid in alcohol, obtained in over 100 determinations only minute quantities of stearic acid and in many cases none at all.

This low percentage of stearic acid should rank with the high percentage of soluble fatty acids, as one of the characteristic differences between butter and other animal fats.

### ANALYSIS OF THE SOLUBLE ACIDS.

A great many methods have been devised for the analysis of a mixture of the lower soluble fatty acids, but very few of them seem practicable in actual work. The method of fractional distillation, which suggests itself perhaps first of all, does not give good results when working with a small quantity of acids, the principal difficulty which we have found being that of not securing a wide enough range in the character of the several fractions.

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* *Vid. op. cit.*, p. 227.

†Analyst, No. 249, p. 321.

‡*Ibid*, p. 322.

No more satisfactory were the methods based upon the difference in the chemical affinities of the various acids.* A neutralized solution of the mixed soluble acids was decomposed with successive portions of tenth-normal sulphuric acid, the liquid being subjected to distillation after each addition of acid. The various distillates were neutralized with tenth-normal barium hydroxide and the mean molecular weights of the acids in each fraction determined. A difference was found in the acids of the several successive distillates, but not a distinctive one, the several molecular weights varying only from two to three units. The theory of the method is borne out, but imperfectly. In one experiment the mean molecular weight of the acids in the first fraction was 102.7; the succeeding fractions gave in their order 99.4, 96.8, 94.8, 93.9, 91.2, and 88.7. It is seen that the mean molecular weights of the acids in the successive distillates decrease until we have practically pure butyric acid in the final fraction; the differences are too small, however, to form any basis for calculations.

The method of Duclaux,† based upon the difference in ratio of vaporization of the various acids from their solution, did not appear adaptable to the present instance where more than two acids were present.

The following method, worked out by the writer, was found to give a considerable range in the character of the different fractions, with but little trouble of execution; it is based upon the difference in the solubility‡ of the various lower homologues in water at different temperatures.

One gram of the mixed acids is weighed out into a fifty cc. flask and treated with twenty-five cc. of distilled water, previously cooled to nearly 0° C. The flask is placed in a beaker of ice and agitated frequently for about five minutes; the contents of the flask are then poured into a small filter placed in a funnel surrounded by ice, and the flask rinsed out with small portions (five cc.) of the cold water, the rinsings being poured upon the filter and allowed to run into a beaker holding the original filtrate. Not more than twenty-five cc. of water are used for the washing. (Fraction 1) The acids left on the filter are washed back into the flask with about twenty-five cc. of distilled water at 30° and, after being kept at this temperature for five minutes with frequent shaking, again filtered. The flask is rinsed out and the acids on the filter washed as before with small quantities of water (about twenty-five cc. in all) at 30°, the combined filtrate and washings constituting Fraction 2. The acids remaining on the filter are then treated successively in the same manner with water at 60° and 95°, Fractions 3 and 4 being thus obtained.*

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*Allen: Commercial Organic Analysis, third edition, Vol. I, p. 487.

†Duclaux: Ann. Chem. Phys. [5], **11**, 233.

‡Storer (Dictionary of Chemical Solubilities) gives the following:

Butyric acid soluble in water in all proportions:
Caproic acid soluble in 96 parts of water at 7° C.
Caprylic acid soluble in 400 parts of water at 100° C.
Capric acid soluble in 1000 parts of water at 20° C.

The various fractions are next titrated with standard tenth-normal barium hydroxide, using phenol-phthalein as indicator; the solutions of the barium salts are evaporated to dryness in weighed platinum dishes, and the residues dried to constant weight at 100°. From the weight of the residue and the weight of barium oxide contained therein, the mean molecular weight of the acids in each fraction is determined.† The amount of barium oxide in the residue can be calculated either from the volume of solution used to neutralize the acids, or by igniting the residue with sulphuric acid and weighing the barium sulphate.

In one experiment, conducted by the method just described, there were found for the different fractions the following results:

*Table VIII.*

| | Temperature of water used for washing. | Mean molecular weight of acids. |
|---|---|---|
| Fraction No. 1, | 5° C. | 91.4 |
| Fraction No. 2, | 30° C. | 113.1 |
| Fraction No. 3, | 60° C. | 123.6 |
| Fraction No. 4, | 95° C. | ...... |

The quantity of acids left after treating with water at 60° amounted to only a few milligrams and so was insufficient for an accurate molecular weight determination.

The weight of acids in each fraction can be found from the formula

$$W = \frac{Mn}{10{,}000},$$

in which $W$ equals the weight in grams of acids, $M$ the mean molecular weight of the acids, and $n$ the number of cubic centimeters of tenth-normal alkali used for their neutralization.

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*The physical characters of the acids are observed to change during the process of washing. After the removal of the first fraction the acids lose their mobility and acquire a thick, oily consistency. The strong rancid smell, characteristic of butyric acid, entirely disappears with the removal of the second fraction, while the residual acids possess a very peculiar odor, resembling somewhat that of perspiration.

†This Journal, **21**, 628.

If we assume that only two acids are present in each fraction, an assumption* probably not very far from true, the percentage of each acid can be calculated from the mean molecular weight according to the general formulas already given. For a mixture of butyric ($B$) and caproic ($C$) acids,

$$B=\frac{8800\ (116-m)}{28\ m};$$

$$C=\frac{11600\ (m-88)}{28\ m}.$$

For a mixture of caproic ($C$) and caprylic ($C_1$) acids,

$$C=\frac{11600\ (144-m)}{28\ m};$$

$$C_1=\frac{14400\ (m-116)}{28\ m}.$$

Several analyses of the soluble acids from butter-fat conducted by the method described gave the following average composition:

| | Per cent. |
|---|---|
| Butyric acid, | 65.28 |
| Caproic acid, | 25.00 |
| Undetermined, | 9.72 |

The mean molecular weight of the undetermined acids can be calculated from the equation,

$$\frac{65.28}{88}+\frac{25.00}{116}+\frac{9.72}{x}=\frac{100}{98},$$

from which $x=154$. This value, falling between 144 and 172, would indicate that the undetermined acids consisted of caprylic and capric. From the mean molecular weight ($m$) the percentages of caprylic ($C_1$) and capric ($C_2$) acids can be calculated as follows:

$$C_1=\frac{14400\ (172-m)}{28\ m};$$

---

*The wide difference in the solubility of the lower acids in water would almost preclude the possibility of finding more than two acids in each fraction. There is, however, this possibility, which experiments would seem to indicate, that the solubility of the higher acids in water is somewhat greater if lower acids are present. This is a point well worth investigation.

$$C_2 = \frac{17200\ (m-144)}{28\ m}.$$

In the undetermined residue of 9.72 per cent. we find from the above formulas sixty parts of caprylic and forty parts of capric acid, or 5.83 per cent. caprylic and 3.89 per cent. capric in the total mixture of soluble acids.

Calculating the analysis to the 8.35 per cent. of soluble acids in the original butter-fat we obtain:

| | *Per cent. |
|---|---|
| Butyric acid, | 5.45 |
| Caproic acid, | 2.09 |
| Caprylic acid, | 0.49 |
| Capric acid, | 0.32 |
| Total, | 8.35 |

### SUMMARY.

The results of the analysis of the mixed acids from the butter-fat examined, together with the equivalent percentages of tri-glycerides, are given in the following table:

*Table IX.*

| Acid. | Percentage of acid. | Percentage of triglycerides. |
|---|---|---|
| Dioxystearic, | 1.00 | 1.04 |
| Oleic, | 32.50 | 33.95 |
| Stearic, | 1.83 | 1.91 |
| Palmitic, | 38.61 | 40.51 |
| Myristic, | 9.89 | 10.44 |
| Lauric, | 2.57 | 2.73 |
| Capric, | 0.32 | 0.34 |
| Caprylic, | 0.49 | 0.53 |
| Caproic, | 2.09 | 2.32 |
| Butyric, | 5.45 | 6.23 |
| Total, | 94.75 | 100.00 |

---

*In connection with these percentages for the soluble acids it will be of interest to quote the results of two French chemists:

Duclaux (Compt. rend., **102**, 1022) found in eight samples of butter examined 3.38 to 3.60 per cent. butyric and 2.08 to 2.26 per cent. caproic acid. Violette (Compt. rend., **111**, 345) found for good butter 5.32 to 6.06 per cent. butyric and 3.22 to 3.66 per cent. caproic acid. Apparently no attempts were made by either of these chemists to determine the caprylic and capric acids.

For other results see Table V.

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Other bodies, such as coloring-matter, lecithin, cholesterin, phytosterin, etc., which occur in butter-fat in only minute quantities, have not been considered in the above analysis. These substances go to make up the unsaponifiable matter of butter-fat, the total amount of which we have found to be only about one-tenth per cent.

We have made an elementary analysis of butter-fat and find the agreement between the actual percentages of carbon, hydrogen, and oxygen, and the theoretical figures as calculated from the percentages of the various glycerides in the preceding table, to be very close.

| | Carbon. | Hydrogen. | Oxygen. |
|---|---|---|---|
| Actual, | 75.17 | 11.72 | 13.11 |
| Theoretical, | 74.86 | 11.71 | 13.43 |

The close agreement between these two sets of results would indicate that the figures expressing the percentages of acids and glycerides in Table IX are not very far removed from the truth.

## THE GLYCERIDES OF BUTTER-FAT.

Experiments of Bell,* Blyth,† and other chemists indicate that there are certain glycerides in butter-fat of a complex nature; that instead of simply one acid we may have two or even three different acid radicals in the same molecule.

If a mixture of tributyrin, tripalmitin, and triolein be prepared and treated with alcohol, it is possible to extract the tributyrin completely. With butter-fat, on the other hand, such an extraction cannot be made, a fact due without doubt to the butyric acid being combined with certain higher fat acids to the same glycerol radical.‡ In confirmation of this, Blyth and Robertson|| have isolated from butter-fat a crystalline glyceride of the formula

$$C_3H_5(C_4H_7O_2)\ (C_{16}H_{31}O_2)\ (C_{18}H_{33}O_2),$$

a mixed ester of butyric, palmitic, and oleic acids,

While a part of the butyric, palmitic, and oleic acids in butter-fat is no doubt bound up together in one molecule, it is also certain that these acids exist in glycerides of a different nature. Experiments seem to indicate that there are present glycerides which contain at

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*Allen: Commercial Organic Analysis, third edition, Vol. II, Part I, p. 180.

†Blyth: Foods; Their Composition and Analysis, fourth edition, p. 340.

‡Benedikt: Analyse der Fette, third edition, p. 544.

||J. Lond. Chem. Soc., Proceedings (1889), 5.

least two radicals of one acid in the same molecule and probably three. Tripalmitin certainly exists and has been isolated by us in a state of comparative purity. The separation of all the various glycerides is a problem at present beyond the power of the chemist. It is only possible to make a few rough separations and from certain analytical data draw some general conclusions.

If a melted butter-fat is allowed to stand for some time at about 25° C., a crystalline deposit will separate out. By filtering we obtain two portions—a clear transparent oil, the so-called butter-oil, and a solid mass comprising all the glycerides of higher melting-point. If the butter-oil is cooled another deposit will form; by repeating the process of filtering and cooling, the congealing point of the oil can be reduced from 25° C. to below 10° C. These different fractions of oil will be found to differ in chemical as well as physical properties, as can be seen from the following table:

*Table X.*

| Congealing-point. | Iodine number. | Saponification number. |
|---|---|---|
| 25° C., | 35.05 | 233.0 |
| 12° C., | 39.24 | 234.0 |
| 9° C., | 40.95 | 235.6 |

The increase in the iodine and saponification numbers, as the congealing-point decreases, is due to an increase in the percentages of oleic and the soluble acids. The quantity of soluble acids increases much faster than the saponification number indicates, since the increase in oleic acid tends to keep this constant down.

The butter-oil of 9° congealing-point contains, according to its iodine absorption, over forty-five per cent. oleic acid, which quantity is considerably in excess of the percentage required by such a glyceride as that of Blyth and Robertson. Indications would point to the presence of glycerides containing at least two radicals of oleic acid in the molecule, and there is no reason to doubt the existence of triolein itself.

The solid mass left on the filter after removing the butter-oil, still contains a high percentage of oleic acid; it resembles butter-fat itself in outward appearance. The body is somewhat harder, however, than butter-fat, possessing also a higher melting-point and lower content of soluble acids. For want of a better name, we have termed this residue, left after removing the oil, butter-palmitin. The relation between the constants of butter-oil, butter-palmitin, and the original butter-fat can be seen from the following table:

*Table XI.*

| | Melting-point. | Saponification number. | Iodine number. | Reichert number. |
|---|---|---|---|---|
| Original butter-fat, | 33° | 231 | 31.00 | 15.30 |
| Butter-oil, | *25° | 233 | 33.05 | 18.18 |
| Butter-palmitin, | 38° | 228 | 27.66 | 11.23 |

By subjecting the butter-palmitin to repeated crystallizations from some suitable solvent (chloroform was found to be the best), it is possible to remove practically all of the oleins and lower glycerides and to obtain almost pure tripalmitin itself. The body possesses a beautiful, white, flaky appearance, crumbles readily between the fingers, and leaves no oily spots when spread on paper. Traces of oleic, stearic, and lower soluble acids are generally present as impurities. A specimen of the glyceride gave a saponification number of 207; the saponification number of tripalmitin, according to theory, is 208.

If we treat butter-fat with hot ninety-five per cent. alcohol, then cool, filter, and evaporate the alcohol, a small quantity of a gum-like fat is left. A body so obtained melted at 22.5° C., gave a saponification number of 257, an iodine number of 26.15, and yielded about seventy-nine per cent. insoluble and fourteen per cent. soluble acids. The small percentage of the body obtained and its high saponification number (higher than that required for an oleopalmitobutyrin), would point to glycerides containing more than one radical of the lower acids.

In conclusion, the most that we can say is that, while the evidence is strongly in favor of the existence of complex glycerides, there are equally good reasons for believing in the existence of simpler bodies. An analysis of the fatty acids from the different fractions of the butter-oil and butter-palmitin would throw much light upon the constitution of the glycerides contained therein; for such work, however, our time has been too limited. We hope, if possible, in the future to continue our work in this direction.

## NOTE.

Inasmuch as the reliability of the analyses, contained in the foregoing paper, is dependent to a great extent upon the accuracy of certain chemical methods, a word should be said in regard to the extent of error which is involved in work of the latter kind.

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*Congealing point.

Nearly all of the calculations concerning molecular weights and percentages were based upon the determination of two constants, the saponification number and the iodine absorption. Wherever possible, duplicate, and in some cases triplicate, determinations of these constants were made. The difference between two detrminations of the saponification number rarely exceeded ± 1, and the error between duplicate determinations of the iodine absorption was seldom greater than ± 0.1; these differences would affect only slightly the calculation of the mean molecular weights and percentages.

In standardizing the different solutions used for the volumetric work we have employed a few methods, which for speed and accuracy we think superior to some other processes in more general use; we will therefore mention them briefly in this connection.

Tenth-normal barium hydroxide is standardized by evaporating a measured quantity (twenty to fifty cc.) in a weighed platinum dish with a slight excess of dilute sulphuric acid, igniting the residue, and weighing the barium sulphate.

Tenth-normal sulphuric acid is standardized in a similar way. Twenty cc. of the acid are measured from a burette into a weighed platinum dish and the solution carefully neutralized with tenth-normal barium hydroxide, using phenol-phthalein as indicator; the liquid is evaporated to dryness, the residue ignited, and the weight of barium sulphate determined. The weight of barium sulphate found divided by 0.2335 will give the factor for the tenth-normal sulphuric acid. In this way the barium hydroxide and sulphuric acid can both be standardized by a single operation. Determinations can be made in one-fourth less time by this process than by the usual method of precipitation and with no difference as regards accuracy of results. The barium hydroxide used should be perfectly pure and free from other alkali; if not C. P. it can be easily purified by recrystallization.

The two tenth-normal solutions just mentioned can be used for standardizing the half-normal alcoholic potash and half-normal hydrochloric acid employed for determining saponification numbers. Another method, which we have been accustomed to apply as a check, has proved very successful in the case of standardizing these last named solutions.

Ten cc. of the half-normal potash solution are carefully neutralized with the half-normal hydrochloric acid, using phenol-phthalein, and the number of cubic centimeters used carefully noted; the liquid, after evaporating off the alcohol, is diluted to about fifty cc. and an excess of platinic chloride solution added. The potassium platinichloride is precipitated and determined in the usual way, a Gooch crucible being used for collecting the precipitate. The weight of potassium platinichloride divided by 1.2145 will give the factor for the half-normal alcoholic potash solution; from the number of cubic centimeters of the acid used to neutralize the potash the factor for the half-normal hydrochloric acid is found. Factors obtained for the half-normal solution by precipitation with platinic chloride and by titration against the tenth-normal solutions have always showed a very close agreement.

## III. THE CHEMISTRY OF RANCIDITY IN BUTTER-FAT.

The phenomena attending the development of rancidity in fats have attracted the attention of chemists for many years; even before the beginning of the present century, ere Chevreul had begun his classical "recherches chimiques sur les corps gras," and when the chemical constitution of fats was still unknown, it had been surmised that the physical changes which oils and fats underwent on long keeping were simply the results of oxidation; and this is the view most generally accepted at the present time, notwithstanding the fact that many eminent chemists in the past have sought to explain the development of rancidity in other ways.

From the very complexity of its composition we would suppose butter-fat to be a rather unstable body; if butter-fat is sealed up and preserved in a cold, dark place, it will retain its normal character and appearance for many months, but if kept in a warm locality with free exposure to the air and light, it will very speedily undergo chemical and physical changes and become, as we say, rancid.

By the term "rancidity" is meant not simply, as is generally supposed, a development of free acid (though this is the general concomitant of rancidity), but any chemical or physical change in the character of a fat from the normal. Fats can be rancid without necessarily being very acid;* rancidity, according to the present most commonly accepted understanding of the term, is simply oxidation, and in the early stages of the process butter-fat may lose its characteristic color and smell, and develop an abnormal lardy taste, and still not show an excessive degree of acidity.

That rancidity in butter, as many authorities aver, is primarily the result of the activity of bacteria, is no doubt partly true of whole butter with its lactose, casein, and other constituents to serve as bacterial food, but it is certainly not the case with pure butter-fat which is unable to support micro-organic life. The independent researches of both Duclaux* and Ritsert† prove beyond question that bacteria cannot thrive in a medium of pure fat, and that all changes which take place in fats on keeping are wholly the results of an oxidation, conditioned to a great extent by exposure to light. The distinction between rancid butter and rancid butter-fat should be borne in mind, since the former condition may prevail without the latter. We have paid but little attention to the development of rancidity in whole butter,‡ and will make this a subject for future study. The present work is confined entirely to those changes which the pure fat undergoes after its separation from all impurities.

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*We believe v. Klecki was the first to distinguish between the terms rancidity and acidity. Ztschr. anal. Chem., 34, 633 (1895).

The three factors most active in the production of rancidity in fats are openness to air, exposure to light, and degree of warmth. Given sufficient time, decomposition may occur with the suppression of any one or even two of these elements, but it is of course most rapid when all three conditions are favorable.

In the development of rancidity in butter-fat, under the usual conditions named above, there are observed first of all several changes as regards color, odor, taste and general appearance. The sample examined begins first to acquire a lighter color; this change appears first on the surface, and the parts most exposed to the light, from which points the action spreads slowly downward until finally the whole mass has become bleached.||

With this loss of color we notice also the development of a lardy odor and taste; as the period of rancidity advances the odor increases in pungency, while the taste, which at first was not markedly acid, becomes exceedingly burning and unpleasant. In addition to the above, we observe some changes in consistency; the sample, which originally was firm and solid in texture, begins to take on a granular look and finally turns, after many months, into a semi-solid pasty mass.

If we determine the various constants of a butter-fat at different periods of rancidity, we notice still other important changes, as can be seen from the following table:

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*Annal. de l'Institut Pasteur, 1888.

†Untersuchungen über das Ranzigwerden der Fette.

‡Lactic acid is always found in both fresh and rancid butter, but never in rancid butter-fat. We have found 0.08 per cent. of lactic acid in fresh butter made from ripened cream, and 0.12 per cent. in a rancid butter. The latter sample also contained 0.23 per cent. of free volatile acids, having a mean molecular weight of 94, to which acids the rancid odor and taste of the butter were no doubt largely due.

The statement frequently met with that rancidity in butter is produced by the action of a butyric ferment upon the fat with the formation of butyric acid, is not warranted. It is a well-known fact that milk sugar may pass by fermentation through lactic into butyric acid, and there is every probability that, under favorable conditions, much of the lactose in butter is converted in this way into volatile acid products.

The part which bacteria play in the spoiling of butter has been studied but little up to the present time; the question is one well worth the attention of bacteriologists.

||This observation pertains only to samples of natural color; with butters artificially colored the bleaching is not always evident, showing that certain butter colors are not affected by the development of rancidity.

*Table XII.*

| Age of Sample. | Degrees rancidity. | Acid number. | Saponification number. | Ether number. | Reichert number. | Iodine number. | Oleic acid—Per cent. |
|---|---|---|---|---|---|---|---|
| Fresh, | 0.9 | 0.48 | 228.1 | 227.6 | 15.63 | 34.95 | 38.79 |
| 1 week, | 2.3 | 1.28 | 230.3 | 229.0 | 15.80 | 34.55 | 38.35 |
| 1 month, | 19.4 | 10.90 | 241.0 | 230.1 | 17.00 | 28.40 | 31.52 |
| 2 months, | 51.5 | 28.84 | 260.0 | 231.2 | 18.75 | 14.35 | 15.93 |
| 4 months, | 53.5 | 30.00 | 262.1 | 232.1 | 19.80 | 11.15 | 12.38 |
| 8 months, | 63.2 | 35.38 | 269.3 | 233.9 | 21.13 | 8.55 | 9.49 |

We observe with the development of rancidity, a decided increase in the acid, saponification, and Reichert numbers, a slight increase in the ether number, and a very marked decrease in the iodine absorption.

"Degrees rancidity" is a constant employed by many chemists as another way of expressing the free acid in fats, and is placed in this and succeeding tables only for the purpose of comparison. It was introduced into fat analysis by Stockmeier* and represents the number of cubic centimeters of normal alkali required to neutralize the free acid in 100 grams of fat: the number of cubic centimeters of tenth normal alkali necessary to neutralize the free acid in 10 grams of fat would also give "degrees rancidity;" one degree rancidity would correspond to an acid number of 0.56.

The effects of rancidity upon the composition of butter-fat are also shown by Table XIII, where the chemical constants of four different samples are given in both the fresh and rancid conditions.

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*Vierteljahrsschrift Nahr. und Genussmittel (1889), 428. According to Stockmeier, a butter-fat showing more than eight degrees rancidity should be condemned as unfit for use. Chemists have recognized the impossibility of fixing any such arbitrary standard as this; a butter-fat may show only two or three degrees rancidity and still be offensive to our organs of sense, which latter, we may say, are far superior to any chemical methods in forming judgments as to the palatability of foods.

## *Table XIII.*

| Butter-fat. | Condition. | Degrees rancidity. | Acid number. | Saponification number. | Ether number. | Iodine number. | Oleic acid—Per cent. | Acetyl number. | Insoluble acids—Per cent. | Glycerol—Per cent. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1a | Fresh, ...................... | 0.80 | 0.45 | 229.9 | 229.5 | 33.93 | 37.66 | 4.8 | 87.20 | 12.54 |
| 1b | Rancid, ..................... | 2.18 | 1.22 | 232.3 | 231.1 | 29.96 | 33.26 | 7.6 | 86.80 | 12.40 |
| 2a | Fresh, ...................... | 0.89 | 0.50 | 223.9 | 223.4 | 34.49 | 38.28 | 3.5 | 88.96 | 12.21 |
| 2b | Rancid, 1 month, ........ | 12.66 | 7.09 | 233.7 | 226.6 | 28.69 | 31.85 | 10.9 | 85.06 | 12.02 |
| 3a | Fresh, ...................... | 0.98 | 0.55 | 232.6 | 232.1 | 29.56 | 32.81 | 4.1 | 86.41 | 12.69 |
| 3b | Rancid, 2 months, ....... | 20.95 | 11.73 | 247.7 | 236.0 | 19.76 | 21.93 | 15.1 | 80.42 | 12.35 |
| 4a | Fresh, ...................... | 0.93 | 0.51 | 225.6 | 225.1 | 34.92 | 38.76 | 3.8 | 88.46 | 12.33 |
| 4b | Rancid, 3 months, ....... | 26.43 | 14.80 | 245.3 | 230.5 | 22.55 | 25.03 | 18.0 | 81.15 | 11.67 |

Sample 1 was exposed for three months to air and light in a cold room during winter; a represents the unoxidized bottom layer, and was unchanged; b represents the upper oxidized part which was bleached and had an abnormal taste and smell. Samples 2b, 3b and 4b were allowed to become rancid in a warm place, with free exposure to air and light.

In addition to the facts previously observed we note from the above table that with the advancement of rancidity there is an increase in the acetyl number and a decrease in the percentages of insoluble acids and glycerol. Other changes produced in the chemical and physical constants of butter-fat by rancidity will be presented in the course of the article.

### EFFECTS OF RANCIDITY UPON THE ACIDS OF BUTTER-FAT.

It is a well-known fact, and one wholly confirmed by the preceding tables, that the oleic acid is the constituent of butter-fat most susceptible to chemical change; being an unsaturated compound it absorbs oxygen with great avidity at the points of unsaturation, yielding either oxy-compounds or decomposing into simpler bodies of lower molecular weight. It is impossible to express by chemical equations either of these changes, owing to the complexity of the reaction and the great variety of products formed.

By means of oxidizing agents oleic acid has been found to yield not only all the members of the homologous series from formic to capric acid, but also certain dibasic and oxy-acids.* While the oxidation process itself, which takes place with oleic acid in the development of rancidity, is less violent than that produced by artificial means, we may say that the character of the decomposition products is to a considerable extent the same.

A. Scala† detected in a strongly rancid olive-oil formic, acetic butyric, and oenanthylic acids, also several dibasic acids of the type $C_nH_{2n-2}O_4$, among others azelaic and sebacic acids; besides these another acid was isolated which, from the analysis of its barium salt, was identified as dioxystearic acid. The same authority also shows that the saturated acids could take no part in the formation of these decomposition products, since they offer a complete resistance to oxidation; small portions of stearic and palmitic acid, on long standing, were found to suffer under ordinary conditions no change in weight; oleic acid, on the other hand, after ten months' exposure to the air and light, increased in weight over eight per cent. As an additional confirmation of this, it was found that the increase in weight, which different fats underwent on becoming rancid, was in direct proportion to their content in oleic acid.

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*Watts' Dictionary of Chemistry, Edition of 1892, 3, 637.

†Staz. sperim. agr. ital., p. 613 (1897). Abstract in Biedermann's Centrbl. für Agriculturchemie, March, 1899, p. 196.

The amount of oxygen which butter-fats absorb on becoming rancid we have found to vary somewhat with the conditions. A thin layer of butter-fat, exposed in a melted state to the action of air and light, gained at the end of two weeks 1.54 per cent. of the original weight; it then began to lose, and at the end of two months had lost 1.94 per cent. of the weight of the sample when fresh. Chemical change proceeds much faster with fats if melted, so that the preceding example can not be taken as a fair illustration of what takes place under ordinary conditions. The following elementary analysis of two butter-fats, one fresh and the other rancid, gives some information as regards the amount of oxygen absorbed during rancidity.

*Table XIV.*

| Butter-fat. | Condition. | Carbon. Per cent. | Hydrogen. Per cent. | Oxygen. Per cent. |
|---|---|---|---|---|
| 1, | Fresh, | 75.17 | 11.72 | 13.11 |
| 2,* | Rancid, 2 years old, | 73.88 | 11.57 | 14.55 |

These results show that the effect of rancidity is to cause a decrease in the percentages of carbon and hydrogen, with a corresponding increase in the percentage of oxygen. Similar results were secured by Lenz† in the case of fresh and rancid horse-fat.

Inasmuch as the iodine number is dependent upon the amount of oleic acid, it is obvious enough that this constant should show a decrease as the period of rancidity advances. We have given in Tables XII and XIII the percentages of oleic acid corresponding to the various iodine numbers. There is some uncertainty among chemists as to the accuracy of calculating the per cent. of oleic acid from the iodine absorption;* this uncertainty would be still greater in the case of rancid fats, where there is the possibility that other unsaturated compounds besides oleic acid may for the time exist.†

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*This sample, which was badly decomposed, stood during the time indicated in a cool place near a window, where the light could have its full effect.

†Ztschr. anal. Chem., p. 441 (1889).

The increase in the saponification number as the period of rancidity advances, can be explained only by the breaking up of higher acids into acids of lower molecular weight,— an explanation which is confirmed by the decrease observed in the percentage of insoluble acids, and by the increase which takes place in the Reichert number.

It was thought that a determination of the mean molecular weight of the volatile acids from rancid butter-fats would throw some light upon the character of the lower acids formed by decomposition, but the results were in some ways disappointing. The majority of the experiments showed but little difference between the molecular weights of the volatile acids from the frsh and rancid samples, the general tendency seeming to be towards a slight decrease in this constant, as the butter-fat became rancid. The mean molecular weight of the volatile acids formed by decomposition would appear from this to have nearly the same value as that of the volatile acids in the fresh sample; this would bear out the view that, in the breaking up of the oleic acid, several different soluble acids are formed, the lower members of the series apparently being produced in the largest quantity.

The free acid, which soon makes its appearance in all rancid fats, is due not simply to oleic acid and its decomposition products, but to other acids as well. In the development of rancidity there seems to be a gradual breaking up of all the glycerides. Samples of tripalmitin which we have prepared from butter-fat, while much more stable than the parent substance, show after long standing the same tendency to become rancid and develop free acid. This is true of other glycerides as well, the acid part of the molecule splitting off from the glycerol base with the probable disruption of the latter. In the case of complex oleins (oleobutyrin, oleopalmitin, etc.), the changes which so soon effect the oleic acid would no doubt hasten the disintegration of the entire glyceride. The first change which manifests itself in fats on becoming rancid is apparently an oxidation of some oleic acid within the molecule, as changes appear in physical and chemical properties before any considerable development of free acid. Butter-fat No. 1 in Table XIII affords us a good illustration of this; the upper oxidized layer of this sample, when compared with the lower unchanged part, shows a decrease of over four per cent. in oleic acid, and an increase of nearly three units in the acetyl number, while the acid number of the rancid portion appears but eight-tenths higher than that of the unchanged fat.

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*For discussion of this point consult Wiley's Agricultural Analysis, 3, 367. See also p. 229 of this Report.

†Such an error would not alter the main facts of the case, however, as the effect would be to magnify rather than diminish the actual percentage of oleic acid.

A determination of the iodine absorption of the free insoluble acids throws some light upon the proportion of free oleic to other acids. 100 grams of a rancid butter-fat were shaken with an equal quantity of hot ninety-five per cent. alcohol. After cooling completely in ice-water, the alcoholic solution was poured through a filter and exactly neutralized with a dilute solution of potassium hydroxide, using phenol-phthalein. The solution was then heated on the steam-bath until all alcohol was evaporated, when the residue was treated with 100 cc. of hot water. The soapy solution, after standing on the bath for a little while to allow any fat which may have been removed by the alcohol to rise, was filtered, cooled and thoroughly extracted with ether to remove all traces of unsaponified matter. An excess of dilute hydrochloric acid was then added to decompose the soaps, and the insoluble acids collected in the usual way.

The iodine number of the free insoluble acids obtained from a rancid butter by this process was 18.47, corresponding to 20.50 per cent. of oleic acid. Thum* found in experiments with palm and olive oils that the free fatty acids in rancid oils contained oleic acid in almost exactly the same proportions as in the neutral fat. Similar results were obtained by Spaeth† in the case of rancid lards. Such experiments show that the method, so commonly practiced, of calculating the total acidity of rancid fats to oleic acids alone is by no means accurate.

The amount of free volatile or soluble acids in rancid butter-fats is much smaller than might be expected. A comparison of the acid numbers, and the acid numbers for the water-soluble acids alone, indicates that in the early stages of rancidity at least, the free soluble acids bear to the total free acids a relation smaller than that existing between the soluble acids and total acids of normal butter-fat. The following table will make this clearer:

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*Ztschr. angew. Chem., 482 (1890).

†Ztschr. anal. Chem., 471 (1896).

*Table XV.*

| Butter-fat. | Character of sample. | Total acid number ($t$). | Water soluble acid number ($s$). | Relation $\frac{s}{t}$ |
|---|---|---|---|---|
| 1, | Rancid, 1 month, | 7.09 | 0.84 | 0.1184 |
| 2, | Rancid, 2 months, | 11.73 | 1.57 | 0.1338 |
| 3, | Rancid, 8 months, | 33.58 | 5.99 | 0.1664 |
| Total acids of butter-fat, | | [*]228.5 | [†]40.5 | 0.1772 |

The determination of the value $t$, or ordinary acid number, has already been described[‡] and need not be mentioned here. The value $s$, or water soluble acid number, represents the milligrams of potassium hydroxide necessary to neutralize the free water-soluble acids in one gram of fat, and is found by washing about ten grams of the rancid fat with successive portions of boiling distilled water until all acid is removed, and then titrating the filtrate with tenth-normal alkali.

It is seen from the preceding table that the value $\frac{s}{t}$ increases with the period of rancidity, and approaches the relation existing between the total and soluble acids of normal butter-fat; this relation would no doubt be equaled or even exceeded by fats in a very advanced stage of rancidity. The results in Table XV confirm the statement of Bondzynski [||] and Rufi that rancidity in butter-fat is due principally to the formation of free insoluble acids, and that free volatile or soluble acids are not found to any extent except in a very advanced stage of decomposition.[§] This would not only indicate that the glycerides of the soluble acids in butter-fat are the most stable, but also leads to the following very pertinent question. If the statement previously made in regard to the breaking up of oleic acid into lower soluble acids be correct, *why is it that these acids do not appear to any great extent in the free condition?* That such acids are apparently formed was shown in Table XII by the increase in the Reichert number which fats undergo on becoming rancid, and that they are formed to a considerable extent, seems evident from the decrease which takes place in the percentage of insoluble acids, as is seen from Table XIII.

There are several possible ways of explaining this non-appearance of the soluble acids formed by decomposition. There is the possibility that the oleic acid, when in the glyceride form, may split up into a soluble and an insoluble acid, the soluble acid remaining in combination with the glycerol base; this hypothesis, however, does not seem a tenable one since a large amount of free oleic acid is found in rancid fats, as was shown by a preceding experiment.* There is also the possibility that esters of the soluble acids may in some way be formed, but this view seems no more plausible than the other; such esters have been found in whole butter,† but we have not been able to detect their presence in rancid fats.

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[*] The average saponification number of butter-fat. Table I, p. 208.

[†] The milligrams potassium hydroxide required to saponify the soluble acids in one gram average butter-fat. *Ibid*, p. 221.

[‡] Cf. p. 209.

[||] Ztschr. anal. Chem., 1 (1890).

[§] Spaeth found the same true of rancid lard. *Ibid*, 479 (1896).

The best explanation of this difficulty which we have been able to arrive at is the following: The first products formed by the decomposition of oleic acid are not of an acid but of an aldehyde nature: these aldehyde bodies are further changed by oxidation into soluble acids, but this takes place only in a very advanced stage of rancidity, which would explain the fact, already referred to, that free soluble acids are not formed to any great extent except in rancid fats of considerable age. By the action of alcoholic potash, aldehydes are decomposed into acids, and small quantities of dark resinous compounds;‡ this would account for the fact that the soluble acids of decomposition do not appear until after saponification, and would also explain the brown coloration which all rancid fats undergo when treated with alkalies.

The presence of aldehydes in rancid fats is indicated on other than theoretical grounds. The cocoanut-like odor, so peculiar to butter-fat in the early stages of rancidity, and the very pungent smell developed later, are probably due to aldehyde products. Spaeth|| has called attention to the reducing action which all rancid fats have on Becchi's silver solution as an evidence of these bodies, while E. von Raumer§ has detected their presence by the aid of Schiff's reagent. The latter test we have found to be one of extreme delicacy.

Schiff's reagent is prepared by saturating a solution of rosaniline acetate with sulphur dioxide gas, and allowing it to stand in a stoppered bottle until completely decolorized. In making the test about one cc. of the melted fat is placed in a test-tube with ten cc. of hot water and thoroughly shaken; one cc. of the reagent is then added and the contents of the tube shaken up a second time. If aldehydes are present the fat and liquid underneath will be colored a splendid violet,—the intensity of the coloration being proportional to the rancidity of the sample. Fresh butter-fat gives no test with Schiff's reagent, even after many hours' standing; with

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*This article, p. 251. Indications are that most of the changes which affect the oleic acid take place after the latter has been set free.

†Amthor: Ztschr. anal. Chem., 10 (1899).

‡Watts' Dictionary of Chemistry, second edition, **1**, 111.

||Ztschr. anal. Chem., 487 (1896).

§*Ibid.*, p. 487.

fats of moderate rancidity the coloration varies from pink to a bright cherry-red, while with very old and rancid specimeents the layer of melted fat is colored a very dark purple, the liquid underneath being a deep violet. The fact that both fat and liquid were colored would show that aldehydes were present in both soluble and insoluble forms. After sapinofying a rancid fat and decomposing the soap solution with an excess of hydrochloric asid, the Schiff test was applied with negative results,* thus proving beyond all doubt that the action of alkalies is to completely destroy all compounds of an aldehyde nature.

The existence of the aldehydes in rancid fats, and their behavior with saponifying agents, explains another point which we have not yet referred to in connection with Tables XII and XIII. It will be seen from these tables that with the development of rancidity there is a noticeable, but not excessive, increase in the ether number. The true ether number of a rancid fat, representing as it does the milligrams of potassium hydroxide necessary to saponify the neutral fat in one gram of substance, would naturally be lower than that of a fresh sample, since with the breaking up of the glycerides the quantity of neutral fat becomes steadily less.† The presence of aldehydes, however, causes a vitiation in the true ether number; these bodies are not affected in the determination of the acid number, but when the alcoholic potash is added in excess for the determination of the saponification number, the aldehydes, as has been shown, are decomposed into acids, to neutralize which an excess of potassium hydroxide is required greater than that necessary to saponify the neutral fat alone. This vitiation of the ether number is much greater than the tables indicate, owing to the fact just mentioned that the true ether number of a fat steadily decreases with the advancement of rancidity.

We have already alluded to the fact that oxy-acids are found in all butter-fats irrespective of age, and the statement was made in a previous article that the low acetyl number, which fresh futter-fat shows, and the steady increase of this constant with age, suggest that these compounds are entirely after-products, and do not exist in the milk-fat before secretion. Experiments already mentioned‡ indicate that the oxy-acids are derived entirely from oleic acid, dioxystearic acid being principally formed.

The following table, compiled from results given in Tables XII and XIII, offers a few interesting comparisons, and gives some idea of the probable manner in which the oleic acid of butter-fat is decomposed.

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*The insoluble acids were slightly tinged, but strange to say the coloration was not as pronounced as with the acids from fresh butter-fat. We attribute this reaction in the insoluble acids to a slight decomposition of the oleic acid subsequent to the saponification.

†This supposition is confirmed by the decrease which takes place in the percentage of glycerol.

‡By Scala, this article, p. 248.

*Table XVI.*

| Butter-fat. | Condition. | Oleic acid—Per cent. | Insoluble acids—Per cent. | Loss in oleic acid—Per cent. | Loss in insoluble acids—Per cent. | Acetyl number. | Increase in acetyl number. | Increase in oxy-acids.—Per cent.* |
|---|---|---|---|---|---|---|---|---|
| No. 1,.... | Fresh, ............... | 38.28 | 88.96 | .......... | .......... | 3.5 | .......... | .......... |
| No. 1,.... | Rancid, ............... | 31.85 | 85.06 | 6.43 | 3.90 | 10.9 | 7.4 | 1.73 |
| No. 2,.... | Fresh, ............... | 32.81 | 86.41 | .......... | .......... | 4.1 | .......... | .......... |
| No. 2,.... | Rancid, ............... | 21.93 | 80.42 | 10.88 | 5.99 | 15.1 | 11.0 | 2.51 |
| No. 3,.... | Fresh, ............... | 38.76 | 88.46 | .......... | .......... | 3.8 | .......... | .......... |
| No. 3,.... | Rancid, ............... | 25.03 | 81.15 | 13.73 | 7.31 | 18.0 | 14.2 | 3.23 |
| No. 4,.... | Fresh, ............... | 38.79 | 87.72 | .......... | .......... | .......... | .......... | .......... |
| No. 4,.... | Rancid, ............... | 9.49 | 72.03 | 29.30 | 15.69 | .......... | .......... | .......... |

We observe from the above table that the loss in insoluble acids accounts for but little more than half the loss in oleic acid; the ratio seems to be a fairly constant one, and averages about fifty-five per cent. This figure, then, may be taken to represent approximately the amount of oleic acid in the loss which is converted into lower soluble acids.† Calculating the increase in the acetyl numbers to dioxystearic acid will make up about twenty-five percent. more of this loss in oleic acid, thus leaving about twenty per cent. still unaccounted for; the formation of insoluble aldehyde products‡ during the saponification may explain this discrepancy.

Owing to the formation of oxy-acids the chemical and physical characteristics of the insoluble acids from butter-fat suffer marked changes with the development of rancidity. The following constants were determined on the insoluble acids of butter-fat No. 4 in the preceding table:

*Table XVII.*

| Condition of Butter-fat. | Mean molecular weight of insoluble acids. | Melting-point of insoluble acids. |
|---|---|---|
| Fresh, ............................................................ | 260.2 | 40.2° C. |
| Rancid, ............................................................ | 273.7 | 44.7° C. |

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*Calculated as dioxystearic acid by the formula, $x = \frac{100\ cm.}{a\ (56100 - 42c)}$. *Cf.* p. 235.

†Including those already existing and those formed by the action of alkali on the aldehydes.

‡The presence of aldehyde condensation products, resin, etc., which are always formed by alcoholic potash, would produce error in the determination of the insoluble acids. The insoluble acids from rancid butter-fats are invariably colored by these bodies, the coloration varying from a yellow to a dark brown according to the rancidity of the sample.

These differences are such as one would expect; the increase in the mean molecular weight and melting-point of the insoluble acids, both being the results of the formation of oxy-acids.

## EFFECTS OF RANCIDITY UPON THE GLYCEROL OF BUTTER-FAT.

One of the most disputed points in connection with the rancidity of fats is that concerning glycerol. A large number of chemists hold that, as fats become rancid, glycerol is liberated in the free state, and cite the instance of palm oil, which seems to split up almost quantitatively into its fatty acids and glycerol; in contradistinction to this many chemists, having tested rancid fats for free glycerol with totally negative results, claim that no free glycerol is formed; other chemists, attempting to reconcile these conflicting views, take the somewhat intermediary position, that fats on becoming rancid are decomposed into free acid, and free glycerol, but that the latter is almost immediately destroyed by oxidation.

A quantitative decomposition of a perfectly pure and dry neutral fat into its glycerol and acids, is manifestly impossible, as such a reaction would require the presence of a large amount of water.

$$C_3H_5(RO_2)_3+3H_2O = C_3H_8O_3+3RO_2H.$$
$$\text{Fat} \quad +\text{water}=\text{glycerol}+\text{fatty-acid.}$$

To reason from the analogy of palm oil is not permissible; this oil is abnormal in many ways, containing, as it does, some twelve per cent. of free acid, even when fresh, with a considerable amount of moisture and other impurities.*

The percentage of glycerol in rancid fats canot be calculated from the ether number, owing to the vitiation in this constant previously referred to. The process of separating the glycerol from other bodies, and determining its percentage by direct weighing, is never accurate and would be still less applicable with rancid fats, where the glycerol would be contaminated with various impurities. A statement made by some chemists that fats undergo an increase in the percentage of glycerol on bcoming rancid, is undoubtdly due to some such faulty method of analysis as the above.

The determinations of glycerol in rancid fat made by us were all performed according to the method of Benedikt and Zsigmondy, as previously described.† The results, which are tabulated in Table XIII, all show a decrease in the percentage of glycerol as the butter-fat became rancid, the decrease being proportional to the rancidity of the sample.

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*According to Benedikt the percentage of impurities with different grades of palm-oil ranges from 0.50 to 17.00 per cent. Analyse der Fette, third edition, p. 525.

†*Cf.*, p. 214.

It is impossible to say just how this loss of glycerol is incurred; it no doubt takes place in the separation of the various fatty acids, and there is good reason to suppose that these acids, since they do not occur as anhydrides, have seized upon the glycerol radical for the elements of water necessary to their formation. If this theory be correct, very little if any glycerol would appear in the free condition; we have examined rancid butter-fats for free glycerol by washing with large quantities of boiling water, and testing the filtrate by the Benedikt and Zsigmondy method. Small quantities of oxalic acid were formed, equivalent to from one-tenth to two-tenths per cent. glycerol; this may have been derived, however, from the oxidation of water-soluble aldehydes, as well as from glycerol. We believe a small amount of acrolein is formed from glycerol in the development of rancidity and attribute the pungent irritating odor which all rancid fats give off—especially on being warmed—to the presence of this compound.

## EFFECTS OF RANCIDITY UPON THE PHYSICAL CONSTANTS OF BUTTER-FAT.

The alterations in chemical composition, which butter-fats undergo with age, produce very decided changes upon the physical constants.

It is a well-recognized fact that as rancidity is developed the specific gravity of fats increase. The specific gravity $\frac{40^\circ}{15.5^\circ}$ C. of fresh butter-fat was found to range from 0.9050 to 0.9102; the values of this constant for rancid butter-fats, at the same temperatures of comparison, were considerably higher, and varied between 0.9195 and 0.9252. This increase is easily explained by the fact that in the development of rancidity the oleic acid, of low specific gravity, is changed by oxidation into compounds of greater density. This is in full agreement with the statement of Brühl* that "by the addition of oxygen the specific gravity of bodies always exhibits a marked increase, no matter what the product of oxidation may be, whether acid, alcohol, oxy-acid, or other in character." It is owing to this increase in specific gravity that the viscosity of fats becomes greater, as the period of rancidity advances.

In regard to melting-point rancid butter-fats exhibit the greatest irregularity, and we have finally come to the conclusion that it is impossible to make a satisfactory determination of the melting-point of butter-fats in a very advanced stage of decomposition. In the early period of rancidity the melting-point is somewhat higher than that of the fresh butter-fat; the increase, which is probably due to the formation of oxy-compounds of higher melting-point, is not a marked one, however, the differences ranging from 0.1° to 1.5° C.

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*Ann. Chem. (Liebig), **211**, 128. See note 2, p. 260 of this article.

A quite characteristic phenomenon, observed with some rancid butter-fats, was that of double melting-point. As an example a rancid butter-fat, by the capillary tube method,[*] melted at 24.2° C.; after keeping the temperature at this point for a few minutes the fat solidified again and, on increasing the heat, remelted at 33.4° C.[†] Samples of excessive rancidity do not exhibit this trait; such fats will usually begin to liquefy at from 22° to 24° C., but will remain turbid from insoluble particles, and will not become perfectly clear until the temperature reaches 35° to 40° C. This behavior is probaby due to the presence of two classes of decomposition products; those of low melting-point, such as fatty aldehydes and lower acids, and those of high melting-point, such as oxy-acids. In this way, too, would be explained the peculiar semi-fluid consistency, which very rancid fats acquire, fresh butter-fat, under the same conditions, remaining firm and solid.

The development of free acid, which takes place in rancid fats, has a very marked effect upon the critical temperature of dissolution. This simple test devised by Crismer[‡] is especially valuable in testing fats and merits a brief description in this connection. About one-half cc. of melted butter-fat is placed in a slender test-tube with twice its volume of absolute alcohol. The tube is closed with a cork, through which a thermometer is passed so that its bulb is entirely covered with the solution and does not touch the walls of the tube. The tube and thermometer thus prepared are passed through a tightly fitting cork into a larger tube partly filled with water; the whole is then gently heated, with constant shaking, until the mixture of alcohol and butter-fat becomes perfectly clear. The temperature at which turbidity appears, after allowing the apparatus to cool, is noted as the critical temperature.

Crismer has observed that with rancid butter-fats the critical temperature is materially lowered, and that this lowering is proportional to the acidity of the fat. By neutralizing such products with weak alkali and washing the fat with hot water, the normal critical temperature was found to be restored; we have secured the same result by washing the rancid fat with alcohol.

The mean critical temperature of several fresh butter-fats, examined by us according to the above method, was 57° C.;[||] rancid butter-fats gave results ranging from 45° to 50° C. according to the degree of acidity.

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[*] The official method could not be used with any degree of success, owing to the solubility of decomposition products in alcohol.

[†] Other instances are known of fatty bodies showing double melting-point. Palmitin melts at 50.5° C. Analyse der Fette, third edition, p. 44.

[‡] Bull. Assoc. belge, **10**, 312 (1896. Abstract in Analyst, **22**, 252, 71.

[||] Of the various rapid tests for adulterated butters this is one of the most reliable. Crismer. found for pure butter-fat critical temperatures ranging from 50° to 57° C., and for margarine and mixtures results between 64° and 78° C.

It is very interesting to note the effect which rancidity has upon the refractive power of fats. All observers* agree in this that the refractive index of fat increases with the development of rancidity, but differ as to the explanation of the phenomenon.

Unfortunately we had no refractometer in the early stages of our work, and so no comparative readings could be made on the various rancid butter-fats used in these experiments. Recently, however, we have been able to make a large number of refractometer readings on various fresh and rancid butter-fats, and in all cases found that the rancid samples gave a higher refractive index. The readings were made on a Pulfrich instrument, the yellow sodium ray (*D*) being used.

*Table XVIII.*

| | Range in refractive indices, 30° C. | | Mean. |
|---|---|---|---|
| Fresh butter-fats, | 1.45872 | 1.45922 | 1.45897 |
| Rancid butter-fats, | 1.45982 | 1.45992 | 1.45987 |

Instead of using the refractive index as a means of comparison, we have preferred to use the specific refractive power. The coefficient of refraction varies greatly with the specific gravity, so that a determination simply of the refractive index leaves one very much in doubt as to whether or not any changes observed may not be due wholly to differences in density.

The specific refractive power is calculated from the formula† $\frac{N-1}{D}$, in which $N$ equals the refractive index of the substance and $D$ its specific gravity.

*Table XIX.*

| | Specific gravity $\frac{30^\circ\ C}{15.5^\circ}$ $(D)$ | Refractive index 30° C ($N$). | Specific refractive power $\left(\frac{N-1}{D}\right)$ |
|---|---|---|---|
| Fresh butter-fat, | 0.91260 | 1.45897 | 0.50292 |
| Rancid butter-fat, | 0.92571 | 1.45987 | 0.49677 |

It is seen that the specific gravity and refractive index of rancid butter-fats are higher, but that the specific refractive power is lower. These results are in perfect accordance with the observations of

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*See articles by Spaeth and Scala already referred to.

†Landolt: Ber. d. chem. Ges., **15**, 1031.

Brühl,[*] that by the addition of oxygen the specific gravity of bodies shows a marked increase and that the same change takes place but to a less degree with the refractive index, but that the specific refractive power is always smaller in the body richer in oxygen.[†]

In view of this, since the percentage of oxygen increases in fats as they become rancid, the changes which affect the refractive power find an adequate explanation.

Another important effect of rancidity upon fats is the marked decrease in the calories of combustion. This is a fact which requires but little explanation. Rancidity is in reality only a slow process of combustion, like other forms of oxidation; it is therefore plain that a certain amount of heat is given off by fats in the development of rancidity and that in consequence thereof the original heat-producing power must suffer a decrease.[‡] The following experiments performed on a fresh and rancid butter-fat will illustrate this. A Hempel-Atwater bomb calorimeter[||] was used in the work.

*Table XX.*

| | Chemical Composition. | | | |
|---|---|---|---|---|
| | C.<br>Per cent. | H.<br>Per cent. | O.<br>Per cent. | Calories. |
| Fresh butter-fat, ............................................ | 75.17 | 11.72 | 13.11 | 9366. |
| Rancid butter-fat, ............................................ | 73.88 | 11.57 | 14.55 | 9095. |

## CONCLUSION.

We have attempted to give in the preceding pages a few of the main facts in connection with the subject of rancidity. The point was made in the beginning of this paper that the nature of the chemical and physical changes, which take place in the decomposition of fats, is one largely dependent upon conditions. The results of the present article were obtained under only one particular set of conditions, viz., those most favorable to the production of chemical change. Had the conditions of warmth, light and exposure to the air been varied, a difference no doubt would have been observed in the degree and character of some of the changes produced. Further investigations as to these points are greatly to be desired.

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[*] Die chemische Constitution organischer Körper in Beziehung zu deren physikalischen Eigenschaften. By J. W. Brühl. Ann. Chem. (Liebig), **211**, 121.

[†] More fully expressed in the language of the original. *Ibid.*, p. 128. "Aus dieser Tabelle ergiebt sich, dass durch die Addition von Sauerstoff die Dichte der Körper stets sehr bedeutend zunimmt, gleichgiltig, welche Art von Verbindung, ob Säure, Alkohol, Oxysäure, u. s. w., hierdurch gebildet wird. Gleichzeitig, aber weit schwächer, wächst auch der Brechungsindex. Dagegen ist die auf gleiche Dichte reducirte brechende Kraft, oder das Brechungsvermögen, bei dem an Sauerstoff reicheren Körper stets kleiner."

[‡] Bruhl: *Op. cit. spura.* p. 126. "Die Verbrennungswärme der Körper sinkt sowohl durch Vereinigung derselben mit Sauerstoff, * * * , oder durch Ersetzung von Wasserstoff durch Sauerstoff."

[||] Seventh report of the Storrs Agricultural Experiment Station, Conn., p. 135.

As we found it difficult to make the distinction between normal and abnormal butter-fats a sharp one, so are we perplexed if we try to draw the line between the qualities fresh and rancid. Butter-fat, as fresh as it can possibly be obtained, gives distinct acid and acetyl numbers, and these changes were no doubt initiated before the cream was separated and churned; we may say, therefore, that, in a certain chemical sense, fresh butter-fat itself is rancid. If chemical changes begin thus early, we naturally ask ourselves, to what limits can this process of decomposition in fats go? This is a difficult question to answer for we know of no instances where fats were kept a sufficient length of time to enable any conclusions as to this point being formed. The ultimate products of oxidation would of course be water and carbon dioxide, but under ordinary conditions this result would hardly be reached; we are probably safe in saying that chemical change will not cease until all the glycerides are decomposed and the oleic acid is completely changed; whether or not other changes of a different order, such as the formation of paraffin bodies, may set in, is wholly a matter of conjecture.

Owing to lack of time we were unable to make a closer study of the various decomposition products formed in butter-fat by rancidity; nothing whatever was done toward the separation and identification of the various aldehydes, acids and other bodies produced in rancid fats, and this we feel to be a serious omission to completeness. As we stated at the beginning, these studies upon butter-fat were conducted in a very desultory manner, being pursued only as other laboratory duties permitted; this we offer as an excuse for the very general and fragmentary character of much of our work. We hope if possible in the future to make further studies in this most fascinating field of chemical research.

In conclusion the writer desires to acknowledge the help and encouragement received from various friends. Our thanks are due to Dr. W. Frear for advice and suggestions in the preparation of these papers; to Dr. G. G. Pond of the Department of Chemistry of the College for the use of a refractometer, and to Dr. F. E. Tuttle of the same institution for assistance in making combustions; also to Mr. C. W. Norris of this experiment station, who made many of the determinations of specific gravity and melting-point contained in the tables of these articles, and who also rendered valuable assistance in determining calories of combustion. We also wish to express our indebtedness to Messrs. A. N. Diehl and C. P. Beistle of this station for their kindly aid at various stages of the laboratory work.

# THE CHEMICAL ANALYSIS OF THE APPLE AND SOME OF ITS PRODUCTS.

BY C. A. BROWNE, JR.

In the fall of 1899, the writer was called upon by the Pennsylvania Department of Agriculture, to make a chemical study of the apple and its various products. The results of this investigation have been embodied in Bulletin No. 58 of the Department's publications. For the complete tabulation of all the analyses made in connection with this work, together with the discussion of the results, reference is made to the above bulletin. A brief summary of the results is presented,[*] however, in this connection, preliminary to a more complete description of the methods of analysis employed. The latter, in fact, is the main purpose of the present paper, inasmuch as no description of methods was included in the original bulletin. The methods herein described, while designed especially for the examination of apples and apple products, have been used successfully in a few other instances, and the writer believes that, with a few modifications perhaps, they could be employed in the analysis of any of our common fruits.

*Composition of Apples.*

| | Water. | Reducing sugars. | Sucrose. | Starch. | Ash. | Acid as malic. | Marc. |
|---|---|---|---|---|---|---|---|
| Unripe apples, 2 analyses, .................... | 80.67 | 6.43 | 2.84 | 3.92 | 0.27 | 1.14 | ........ |
| Summer apples, 6 analyses, .................. | 85.00 | 7.10 | 3.36 | [*]1.04 | 0.28 | .68 | ........ |
| Winter apples, 21 analyses, .................. | 83.16 | 8.16 | 4.16 | ........ | 0.26 | .59 | [†]1.85 |

The above analyses represent simply the composition of the edible or fleshy portion of the apple. Those figures, together with other determinations made upon the combined pulp and marc from different varieties of fruit, have furnished the following table.

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[*] This is done with the kind permission of Prof. John Hamilton, Secretary of the Pennsylvania Department of Agriculture.

[*] One analysis.

[†] Eight analyses.

## *Approximate Average Composition of the Flesh of the Ripe Apple.*

| Ingredients. | Percentage. |
|---|---|
| Inorganic. | 84.00 |
| Water, | |
| Ash, | .30 |
| Organic. | |
| Sugars: | 8.00 |
| Reducing sugars, | 4.00 |
| Sucrose, | 0.00 |
| Starch, | |
| Marc: | .90 |
| Cellulose, | .50 |
| Pentosans, | .40 |
| Lignin, | |
| Organic acids: | |
| Free acid as malic, | .60 |
| Combined acid as malic, | 20 |
| Pectin bodies, | .40 |
| Crude fat, | .30 |
| Protein, | 10 |
| Undetermined (tannin, etc.), | .30 |
| | 100.00 |

## *The Chemical Composition of Apple-Ash.*

| Ingredients. | Percentage. |
|---|---|
| $K_2O$, | 55.94 |
| $Na_2O$, | .31 |
| $CaO$, | 4.43 |
| $MgO$, | 3.78 |
| $Fe_2O_3$, | .95 |
| $Al_2O_3$, | .80 |
| $Cl$, | .39 |
| $SiO_2$, | .40 |
| $SO_3$, | 2.66 |
| $P_2O_5$, | 8.64 |
| $CO_2$, | 21.60 |
| Total, | 99.90 |
| Deduct O equivalent to Cl, | .09 |
| Total, | 99.81 |

The above analysis was made upon the combined ashes from many different varieties of apples, the flesh of the fruit being the only part taken for incineration.

### *Composition of Apple Juices.*

| | Specific gravity. | Solids. | Reducing sugars. | Sucrose. | Free acid as malic. | Ash. | Pectin. | Albuminoids. | Rotation Ventzke, 400 mm tube. |
|---|---|---|---|---|---|---|---|---|---|
| Juice from summer apples, 8 analyses, | 1.0502 | 12.29 | 6.76 | 3.23 | 0.72 | 0.29 | *0.12 | *0.03 | —26.67 |
| Juice from winter apples, 4 analyses, | 1.0569 | 13.96 | 8.57 | 3.40 | 0.43 | 0.27 | †0.12 | †0.02 | —45.15 |

The composition of other fruit juices, from analyses made by the writer, is given for purpose of comparison.

| Kind of Juice. | Specific gravity. | Solids. | Reducing sugars. | Sucrose. | Free acid as malic. | Ash. | Pectin. | Albuminoids. | Rotation Ventzke, 400 mm tube. |
|---|---|---|---|---|---|---|---|---|---|
| Strawberry, | 1.0420 | 9.64 | 5.90 | 0.89 | 1.28 | 0.61 | 0.63 | 0.38 | —5.28 |
| Red raspberry, | 1.0463 | 11.01 | 5.13 | 2.31 | 1.44 | 0.60 | 0.88 | 0.75 | +7.32 |
| Black raspberry, | 1.0567 | 13.65 | 9.52 | None | 1.85 | 0.60 | 0.72 | 0.38 | —25.20 |
| Black cherry, very sweet, | 1.1034 | 24.30 | 16.35 | None | 1.47 | 0.30 | 0.30 | 0.63 | —23.80 |
| Red cherry, sour, | 1.0461 | 11.22 | 7.33 | None | 1.32 | 0.57 | 0.25 | 0.56 | —12.96 |

Closely related to apple-juice is what is known as "second pressings," used so extensively at present for jelly making and vinegar stock. It is made simply by wetting apple pomace with water and repressing.

### *Composition of Second Pressings.*

| | |
|---|---|
| Specific gravity, | 1.0376 |
| Solids, | 9.14 per cent. |
| Reducing sugars, | 6.87 per cent. |
| Sucrose, | 1.49 per cent. |
| Ash, | 0.20 per cent. |
| Undetermined (pectin, malic acid, etc.), | 0.58 per cent. |
| Rotation Ventzke, 400 mm tube, | —31.94 |

The composition of completely fermented cider and vinegar is shown by the following figures, compiled from analyses made upon samples of known purity.

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*4 analyses.

†1 analysis.

### *Composition af Cider and Cider Vinegar.*

| | Specific gravity. | Solids. | Ash. | Reducing sugars. | Acetic acid. | Malic acid. | Alcohol. | Pectin. | Albuminoids. | Rotation Ventzke, 400 mm tube. |
|---|---|---|---|---|---|---|---|---|---|---|
| Cider, 6 analyses, .... | 1.0006 | 2.34 | 0.29 | 0.32 | 0.61 | 0.25 | 5.51 | 0.04 | 0.02 | —2.34 |
| Vinegar, 4 analyses,.. | 1.0184 | 2.00 | 0.44 | [*]0.52 | 6.19 | 0.14 | None | 0.17 | 0.01 | [*]—2.01 |

### *Composition of Miscellaneous Apple Products.*

| | Moisture. | Reducing sugars. | Sucrose. | Ash. | Free acid as malic. | Albuminoids. | Pectin. | Marc. |
|---|---|---|---|---|---|---|---|---|
| Evaporated apples, 3 analyses,....... | 27.61 | 32.80 | 19.02 | 1.10 | 4.06 | .87 | ........ | 5.53 |
| Apple butter, 1 analysis, .............. | 52.58 | 37.20 | 1.14 | .97 | 2.52 | .25 | 2.15 | 1.14 |
| Cider jelly, 1 analysis, ................ | 44.53 | 49.50 | 2.18 | 1.39 | 3.61 | ........ | 1.60 | None |
| Apple pomace, 1 analysis, ............ | 70.76 | 8.09 | 2.40 | .49 | ........ | 1.25 | ........ | ........ |

## METHODS OF ANALYSIS.

The methods employed in making the determinations contained in the preceding tables are in many cases simply the ordinary processes described in most books on commercial or agricultural analysis. The methods[†] of the official agricultural chemists were employed as far as possible. Only such departures as it was found advisable to make from the normal methods will be described.

*Determination of Moisture and Solids.*—This, apparently the most simple of all analytical processes, was found at the outset of the work to offer the greatest difficulties. The methods ordinarily prescribed recommend that the material be dried at 100° C., or even higher, until a constancy in weight is attained. In making determinations by any of these methods the writer has found it impossible to obtain any such constancy in weight; the residue would continue to lose, until its percentage became finally much less than the sum of the percentages of the different solid constituents. A decomposition of some kind was indicated and the unreliability of drying at a high temperature clearly shown.

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[*] The writer desires at this point to call attention to a statement made by Doolittle and Hess in a recent number of the *Journal of the American Chemical Society* (Vol. XXII, No. 4, p. 219). It is said that "the solids of pure cider vinegar gave no rotation with the polariscope, and little or no reducing action on Fehling solution after the customary clarification with lead acetate." This is certainly a mistake. Of the many samples of pure cider vinegars examined by the writer at the Penn'a Expt. Station during the past four years, not one has failed to give a decided rotation to the left, when examined in the 400 mm tube of the polariscope, whether previously clarified with animal charcoal or sub-acetate of lead or not.

An unpublished experiment conducted by the writer at this Expt. Station, shows that levulose is the only sugar present in properly fermented cider vinegar, the sucrose and dextrose having both disappeared in the course of the alcoholic fermentation. The acetic fermentation, which sets in before the last traces of levulose have been destroyed, seems to prevent the complete removal of the sugar by alcoholic fermentation, and the percentage of levulose continues, thereafter, nearly constant.

[†] Bull. No. 46, Revised Edition, U. S. Dept. of Agr., Div. of Chem.

The difficulty experienced is undoubtedly due to a breaking up of the sugars of the fruit, principally levulose. This has been found true in the case of other bodies containing levulose, as has been shown by Carr* and Sanborn in their experiments upon "the dehydration of viscous organic liquids." These writers, after making "upward of 5,000 separate determinations, ranging over all the better-known methods and covering such materials as pure sugar and levulose solutions, honey, molasses, molasses "flowers," sorghum, beet and maize juices, etc., etc.," "conclude that it is impossible to dehydrate quantitatively solutions containing levulose without the occurrence of decomposition, if the temperature be 100 °, the environment air, and the pressure equal to that of the atmosphere." The method finally adopted by Carr and Sanborn, to prevent the decomposition of levulose during dehydration, consists in drying the material on pumice stone in flat-bottomed dishes, at 70° C., and a vacuum of 25 inches.

The writer has been unable to find any work relating to the dehydration of fruits, or the products therefrom, in vacuo, but the same necessity would exist for such dehydration as with other levulose containing materials, the presence of levulose in most fruits being sufficiently indicated by the marked levorotation, which the clarified juices give to the plane of polarized light.

In the various analyses, previously recorded, the writer effected dehydration in most cases by drying the material at 70° C., in a vacuum as recommended by Carr and Sanborn, using, however, perforated brass or copper tubes filled with asbestos for absorbing the liquid, instead of pumice-stone in dishes as in the method of the above authorities.

The perforated tubes employed measured 9 cm. long by 2 cm. in diameter. In the case of liquids, fruit juices, cider, vinegar, etc., the tubes are nearly filled with freshly ignited asbestos,—the latter being tightly packed with a rod against the sides in the upper half of the tube, thus leaving a central cavity extending part way into the asbestos. Each tube thus prepared is placed in a glass-stoppered weighing bottle of sufficient size, and the whole weighed. About

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*Bull. 47, U. S. Dept. of Agr., Div. of Chem., p. 134. See also *Jour. Amer. Chem. Soc.*, XVII, p. (23) Proceedings Wash. Sec.

5 cc. of the liquid to be analyzed are then delivered from a pipette into the cavity in the asbestos, the object of the cavity being to secure a rapid absorption and even distribution of the liquid through the asbestos. The weighing bottle is then immediately stoppered and reweighed, the increase in weight being the amount of substance taken. After removing the stopper, the bottle, together with the inner tube, is conveyed to a vacuum drying apparatus, where it is dried in an upright position, at a constant temperature of 70° C. During the first few hours of the drying, a slight current of air is drawn through the vacuum compartment, in order to remove the large excess of moisture at first given off. In the last stages of the drying the air current is decreased and the vacuum kept at about 25 inches. Eight to ten hours are generally sufficient to secure complete dehydration; at the end of this time the weighing bottle is removed from the oven, placed in a dessicator, and when cold, restoppered and weighed.

The bottles are then replaced in the oven and dried for a second period of a few hours to ascertain if constant weight has been secured. The first drying, however, has generally been found sufficient. A longer drying of several days has been found to produce no change in weight, when once dehydration was secured, showing that no decomposition of levulose is produced.

In determining moisture or solids in apples and other fruits the same method is employed, with the exception that the perforated tubes are filled only about one-fourth with asbestos. The grated pulp of the fruit to be analyzed is well sampled and mixed and a small portion of 5 to 10 grams transferred through a short-necked funnel into the tube, when the bottle is restoppered and weighed. The drying is conducted as previously described; the slight amount of liquid, which sometimes oozes out into the weighing bottles does no harm.

In drying fruit products of much consistency, such as jelly, it is best to dissolve a weighed amount of the material in water, before adding to the asbestos, in order to secure a better absorption. The same necessity of drying in vacuo at low temperature exists with evaporated fruit products, such as dried apples. In such cases the use of the inner perforated tube is dispensed with altogether. The finely cut material is weighed out directly in the weighing bottle and the process conducted as already described.

It might be supposed that, with fermented ciders and vinegars, owing to the disappearance of levulose during fermentation, a determination of the solids by the vacuum method at 70° C. and by drying at 100° C. in the usual way would show no decided difference. Such, however, is not the case. With completely fermented ciders and vinegars a constancy in weight is attained by drying at 100° C., but the percentage of solids is invariably less than that obtained by the vacuum method. The following is an example of this; the experiment was performed upon a pure cider vinegar:

| | Per cent. | |
|---|---|---|
| | I. | II. |
| Solids by drying at 100° C, two days, | 1.48 | 1.50 |
| Solids by drying at 100° C, three days, | 1.47 | 1.49 |
| Solids by drying in vacuo at 70° C, two days, | 3.29 | 3.39 |
| Solids by drying in vacuo at 70° C, three days, | 3.28 | 3.39 |

The percentage of reducing sugar was only 0.16 per cent., so that decomposition of levulose does not explain the discrepancy. It may be due partly to the volatilization of glycerol, which is formed during the alcoholic fermentation. Indications, however, point to the presence of other substances, besides levulose, in fruit products, which are decomposable at 100° C.

### *The Calculation of Solids in Fruit Juice from the Specific Gravity.*

The application of this principle, by means of the Brix spindle, in the analysis of juices from the beet and sugar cane is too well known to require mentioning; it has also been applied by Kulisch* in the analysis of apple juices, the degrees Brix or Balling, corresponding to the specific gravity of the juice at 17.5° C., being the percentage of solids. The writer has compared this method of estimating solids with the actual determination, and the agreement has usually been very satisfactory. Instead of using degrees Brix, the solids of juices may be calculated from the formula, 245 (S—1). S being the specific gravity of the juice at 17.5° C. Such methods of estimating solids are of course only applicable in the case of fresh juices, before the beginning of the alcoholic fermentation. The following table gives the percentage of solids, as estimated and actually determined in a number of different juices.

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**Landwirthschaftliche Jahrbucher*, Vol. XIX, 1890, p. 110.

| Kind of Juice. | Specific gravity 17° 5 C. | Degrees Brix. | Solids by formula 245 (S—1). | Actual solids at 70° C in vacuo. |
|---|---|---|---|---|
| | | | Per cent. | Per cent. |
| 1. Apple juice ("second pressings"), | 1.0376 | 9.39 | 9.21 | 9.14 |
| 2. Apple juice, | 1.0474 | 11.73 | 11.61 | 11.36 |
| 3. Apple juice, | 1.0481 | 11.90 | 11.78 | 11.81 |
| 4. Apple juice, | 1.0484 | 11.97 | 11.86 | 11.87 |
| 5. Apple juice, | 1.0488 | 12.07 | 11.96 | 11.71 |
| 6. Apple juice, | 1.0517 | 12.75 | 12.67 | 12.78 |
| 7. Apple juice, | 1.0525 | 12.94 | 12.86 | 12.77 |
| 8. Apple juice, | 1.0539 | 13.26 | 13.21 | 13.29 |
| 9. Apple juice, | 1.0559 | 13.73 | 13.70 | 13.94 |
| 10. Apple juice, | 1.0560 | 13.76 | 13.72 | 12.83 |
| 11. Apple juice, | 1.0568 | 13.94 | 13.92 | 13.84 |
| 12. Apple juice, | 1.0613 | 14.99 | 15.01 | 14.90 |
| 13. Apple juice, | 1.0722 | 17.50 | 17.69 | 16.82 |
| 14. Strawberry juice, | 1.0420 | 10.44 | 10.29 | 9.64 |
| 15. Red raspberry juice, | 1.0463 | 11.47 | 11.34 | 11.01 |
| 16. Black raspberry juice, | 1.0567 | 13.92 | 13.89 | 13.65 |
| 17. Red cherry juice, | 1.0461 | 11.42 | 11.29 | 11.22 |
| 18. Black cherry juice, | 1.1034 | 24.42 | 25.33 | 24.30 |
| Average of all, | ............ | 13.42 | 13.41 | 13.16 |

The formula, as a rule, gives results slightly closer to the actual percentage of solids, except in case of juices of very high gravity, as No. 18 of the preceding table. The difference between actual and calculated results rarely exceeds two or three-tenths of a per cent.; there is occasionally, however, a notable discrepancy as in the case of apple juices No. 10 and 13. Calculating the solids from the gravity of a juice is sufficiently accurate for many purposes; such an estimation is preferable, in any case, to the old method of determining solids by drying at 100°C.

*Ash.*—This was determined according to the official method, about 20 gms. of material were taken for analysis. In incinerating large quantities of material, to obtain ash for the ash analysis, it is necessary to exhaust the charred mass first with water. The insoluble residue is collected on a filter, burned, and this ash added to the residue left on evaporating the aqueous extract. The whole is then heated to a low redness till the ash is white.

*Reducing Sugar.*—This was calculated, in the various analyses given, simply as invert sugar. Strictly speaking this is not correct for the dextrose and levulose of fruit juices are present in by no means equal proportions,—as in apple-juices, where the percentage of levulose is nearly double that of dextrose. Nevertheless, when these sugars are not separately determined, it has seemed to the writer more accurate to consider the reducing sugar as invert rather than dextrose or levulose alone. The invert sugar is calculated from the weight of reduced copper according to the tables of Meissl and

Wein; such small amounts of sucrose as are present in fruit juices, do not affect the accuracy of the determination.

In the determination of reducing sugar in fruit juices 20 cc. of the filtered juice are measured out into a 500 cc. flask, about 300 cc. of water are added, and after neutralizing carefully with NaOH, using phenolpthalein, the volume is completed to the mark. 25 cc. of this solution (1 cc. of original liquid) are taken for the copper reduction. The reduced $Cu_2O$ is filtered in asbestos tubes and, after drying, reduced in a current of hydrogen, and the weight of copper determined. In case of partly fermented juices larger amounts of liquid can be used for dilution. With completely fermented ciders and vinegars, which contain but very little sugar, the liquid after neutralizing needs little, if any dilution. In calculating the percentage of reducing sugar, it is, of course, necessary to take into account the specific gravity of the liquid analyzed.

In determining reducing sugar in apples and other whole fruits, the following method was adopted: 100 grams of the grated pulp are washed on a muslin filter in a large funnel, with repeated quantities of cold water,—the filter being squeezed after each addition of water to hasten the removal of the sugar. The filtrate is caught in a 2,000 cc. flask, and the washing continued until the liquid is nearly up to the mark. After completing the volume, the flask is shaken, and 200 cc. (10 gms. of fruit) of the filtered solution transferred to a 250 cc. flask; this solution is neutralized with soda as before and the volume made up to 250 cc. from which 25 cc. (1 gm. of fruit) are taken for the copper reduction.

The same method is used with evaporated fruit products, as with whole fruit, except that a smaller amount of material is taken for analysis; 25 grams of the finely cut material are treated with 200 cc. of water for several hours in a large beaker until the substance has swollen to a soft pulp. The material is then brought upon the muslin filter, and washed to 2,000 cc. as before.

With fruit jellies, 10 gms. of the material are dissolved in water, neutralized, and made to 1,000 cc.

*Sucrose.*—This was determined in the majority of cases from the increase in the copper reducing power, after inversion with hydrochloric acid. In making the analysis the method of procedure is as follows:

The same amount of solution (juice, aqueous extract of fruit, etc.), is taken as in the determination of the reducing sugars: one-tenth its volume of concentrated hydrochloric acid is added, and the flask placed in a water bath at 70° C. The contents of the flask, after reaching a temperature of 67°-70° C., are kept within this limit for exactly five minutes, when the solution is cooled, neutralized, and made up to the same volume as in determining reducing sugars.

25 cc. of this solution are taken for the copper reduction, the calculation being made to invert sugar as before. The difference between the percentage of invert sugar before and after inversion, multiplied by 0.95 will give the percentage of sucrose.

Sucrose has also been determined in fruit juices by means of the polariscope. 52.096 grams of juice are made to 100 cc. 50 cc. of this solution are clarified with 5 cc. of lead subacetate and the reading taken in the 200 mm. tube at about 20°C. The remaining 50 cc. are inverted with 5 cc. of concentrated hydrochloric acid, as described above, cooled rapidly and diluted to 100 cc. The reading is taken in the 200 mm. tube, at the same temperature as the first solution, clarifying if necessary with animal charcoal. The first or direct reading increased by $\frac{1}{10}$ and divided by $2 = a$, the invert reading $= b$. $100 \frac{(a - b)}{142.4 - \frac{t}{2}}$ = percentage of sucrose, t being the temperature of the solutions at time of reading.

*Levulose and Dextrose.*—In many cases a separate determination of these sugars has been made. Several courses of procedure have been followed according to conditions.

In the presence of both dextrose and sucrose, the levulose was determined by the difference in polarization of the solutions at widely separated temperatures.[*] With juices, etc., the pure liquid is first clarified by means of animal charcoal, and the polariscope reading taken in a 200 mm. tube, first at about 15° C. ($v$), and then at about 85° C. ($v^1$). The tube used should be provided with a metal jacket, through which water of the desired temperature is allowed to circulate. The percentage of levulose $l$ is calculated from the formula.

$$l = \frac{v - v^1}{G\ (t\ x - .0323)}$$

$v - v^1 =$ the algebraic difference between the two readings and if levulose is present, will always be a minus quantity, owing to the fact that the rotation of levulose solutions when heated is deflected towards the right.

$G =$ the specific gravity of the liquid.

$t =$ the difference in temperature between the readings.

The value —.0323[†] represents the deviation (Ventzke), for each degree C. difference in temperature, produced by one gram of levulose in 100 cc.

With fruit jellies, etc., a definite weight of the material

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[*] See Wiley Agric. Analysis, Vol. III, p. 267-273.

[†] This figure was deduced from the general formula of Jungfleisch and Grimbert, which gives the specific rotary power of levulose for any temperature or concentration. The equation is $= -[101.38 - 0\ 56\ t + 0.108\ (c\text{-}10)]$, in which $t$ is the temperature of the solution and $c$ the $[a]$ grams of levulose in 100cc. See Landolt, Das optische Drehungsvermögen, 2 Auflage, p. 524

(20—50 gms.) is dissolved in 100 cc. of water and the solution, after clarifying, polarized at different temperatures as before. In this case the percentage of levulose, or

$$l = \frac{100\ (v - v^1)}{W\ (t\ x - .0323)}$$

W being the grams of substance in 100 cc.

Knowing the percentage of levulose, and the copper reducing power of the solution, the percentage of dextrose admits of calculation. Volumetric determinations by Soxhlet upon solutions of invert sugar have shown that for the same volume of Fehling solution reduced one part of levulose corresponds to 0.924 parts of dextrose. Gravimetric determinations made by the writer upon pure solutions of invert sugar show a ratio somewhat lower than this, as the following table shows. The gravimetric method of Allihn was followed.

| 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|
| Weight of sucrose taken. | Weight of invert sugar therefrom. | Weight of copper. | Corresponding wt. of dextrose (Allihn's table). | Ratio of dextrose to invert sugar. |
| Grams. | Grams. | Grams. | Grams. | |
| 0.2300 | 0.2421 | .4315 | .2313 | 1.047 |
| 0.1533 | 0.1614 | .2950 | .1538 | 1.049 |
| 0.1150 | 0.1211 | .2230 | .1148 | 1.055 |
| 0.0575 | 0.0606 | .1120 | .0570 | 1.061 |

It is seen that the ratio of dextrose to invert sugar increases slightly as the concentration of the solution diminishes; the variation, however, is not sufficient to make any appreciable difference in the calculations. Taking the average of the above determinations, 1 part of dextrose would correspond to 1.053 parts of invert sugar for the same weight of copper reduced. Since invert sugar is made up of equal parts of dextrose and levulose, 1 part of dextrose would correspond to 1.106 parts of levulose for the same amount of reduced copper, or 1 part of levulose would equal 0.90 parts of dextrose.

Knowing the percentage of levulose the percentage of dextrose (d) may be found from the formula

$$d = D - .9\ l.$$

D = percentage of reducing sugar as dextrose, Allihn's method.
l = percentage of levulose as found by polarization.

In the absence of sucrose the writer has calculated the percentages of dextrose and levulose from the rotation and copper-reducing power. The factors necessary to know are P, the specific rotary power, and D, the percentage of reducing sugars as dextrose.

To determine the specific rotary power it is necessary to know the rotation of a known amount of the sample in a tube of definite length. For this purpose in the case of fruit juices, etc., it is best to read the clarified liquid directly in a 400 mm. tube; with more concentrated products 20 gms. of substance are dissolved in water and made to 100 cc. For clarification the writer has used animal charcoal in the majority of cases, though lead sub-acetate answers equally well and in some cases is found necessary. But very little difference has been noticed in the rotation by these two methods of clarification, provided excess of lead solution is avoided. In clarifying with lead the polariscopic reading must of course be corrected for the dilution. In case of a sugar polariscope with a Ventzke scale, the reading must be corrected to angular degrees by multiplying by the factor 0.3468. The formula for calculating the specific rotary power in the case of liquids is

$$P\ (20^\circ C) = \frac{.3468\ v}{4\ G}.$$

$v$ = polariscope reading, Ventzke scale, in 400 mm. tube at 20° C.

$G$ = the specific gravity of the solution.

4 is the length of the tube in decimeters.

If the material is weighed out and made up to 100 cc. by dilution with water the formula becomes:

$$P\ (20^\circ c) = \frac{.3468\ v}{4\ W} \times 100$$

W being the grams of substance taken.

The specific rotary power of a solution being dependent upon the percentages and specific rotary powers of its ingredients, we would have for solutions containing dextrose and levulose alone the formula:

$$53\ d - 90\ l = 100\ P.$$

d and l are the percentages of dextrose and levulose, and 53 and —90 are their respective specific rotary powers at 20° C., the concentration for each sugar not exceeding ten per cent.

Substituting the formula $d = D - .91$ in the previous equation, we obtain:

$$l = \frac{53\ D - 100\ P}{138}$$

As far as the writer has been able to compare them, these two methods of determining levulose have shown a very close agreement, as the following examples, in the case of a partly fermented cider, will illustrate.

Specific gravity of cider = 1.0067 = G.

Rotation of cider at 15° C., 200 mm. tube Ventzke scale = —10.1° = v.

Rotation of cider at 85° C., 200 mm. tube Ventzke scale = —5.5° = $v^1$.

The difference in temperature of the two readings = 70° = t.

Substituting these values in the formula

$$l = \frac{v - v^1}{G\ (t\ x - .0323)}$$

we find l to equal 2.04 per cent.

The percentage of reducing sugars as dextrose was 2.26 = D.

The rotation of the cider at 20° C., 400 mm. tube, Ventzke scale, was —18.8° = v.

The specific rotary power of the cider, from the formula

$$P\ (20^\circ\ c) = \frac{.3468\ v}{4\ G},$$

is therefore —1.62 = P.

Substituting the above values for D and P in the equation

$$l = \frac{53\ D - 100\ P}{138},$$

we find l to equal 2.04 per cent., the same as before.

The percentage of dextrose in the cider, calculated from the formula d = D —.9 l, is 0.42 per cent.

*Starch.*—This substance has been found in all green pomaceous fruits; it no doubt occurs in other classes of fruits in the early periods of their growth, though this is a point which has not been as yet fully investigated. In the ripening of fruits the starch is gradually converted into sugar, and this process continues, even after picking, until no vestige of starch remains. A determination of starch is of course only necessary, when its presence is indicated by the iodine reaction.

The estimation of starch in fruits, depending as it does upon its conversion into dextrose, offers especial difficulties, owing to the large amount of reducing sugars present, and the first step in any process of analysis must consist in the removal of all the sugars before the conversion of the starch is attempted. The process usually recommended consists in washing a weighed amount of the pulp either directly upon a filter, or by decantation upon the same, until all the sugars are removed. This method of procedure has been found by the writer to be extremely tedious, owing to the large amount of washing required and to the tendency, which the pectinous and gummy matters of the fruit have of clogging the filter.

The following process adopted by the writer avoids in great measure this difficulty and, as it is carried out directly in connection with the sugar determinations, effects a considerable saving of time.

100 grams of the finely grated pulp are washed upon a muslin filter with repeated quantities of cold water, until filtrate amounts to 2 liters; the muslin is squeezed after each addition of water, as already described under the determination of sugar. In this way practically all of the starch is washed out of the pulp. The filtrate, after being well mixed, is transferred to a tall beaker or cylinder, where it is covered and allowed to stand in a cool place over night. The finely suspended particles of starch will have completely settled by this time to the bottom of the vessel forming a compact mass. The liquid above the starch is then removed by means of a siphon or decantations down to within a short distance of the precipitate; this solution may be used for the determination of sugars and malic acid.

The precipitate of starch is transferred with small quantities of cold water to a hardened filter paper and washed to remove the last traces of sugar; 100 cc. of water are usually sufficient for this. The starch thus prepared consists of a white crumbly mass, but is not perfectly pure, owing to the presence of some cellular and albumenoid matter. The starch might be determined at this stage with sufficient accuracy by direct inversion with hydrochloric acid as in the Sachsse method, but the writer has preferred to use the more exact process of first hydrolizing with diastase.

A starch determination by means of the diastase method should also be made upon the residue left on the muslin filter after the washing, in case the latter should show any reaction with iodine. The writer has never found the residues to yield more than one or two-tenths per cent. of starch upon the original pulp, so that the determination is rarely necessary if the washing has been properly performed.

The official diastase method* was followed throughout, except as regards the neutralization after the inversion with hydrochloric acid. The writer has always preferred a ten per cent. solution of sodium hydroxide, using phenolphthalein, instead of sodium carbonate as prescribed in the official method; the troublesome frothing incident to the use of the latter substance is thus avoided.

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*Bull. No. 46, Revised Edition, U. S. Dept. of Agric., Div. of Chem.

*Marc.* —This represents that part of the fruit, which is insoluble in water. It is best found in connection with the sugar determination; the residue, left upon the muslin filter after the washing, is transferred to a dish, and dried to a constant weight at 100° c. With the exception of a trace of ash and albumenoid matter, the marc of apples was found to consist almost wholly of cellulose, lignin and pentosans.

In case the percentages of the different marc constituents is desired, the pentosans are best determined by distilling a weighed amount of the dry marc with successive quantities of 12 per cent hydrochloric acid, and precipitating the furfurol in the distillate by means of phloroglucin.[*] The cellulose is separated from the other marc constituents by the chlorination process of Cross and Bevan.[‡] The lignin bodies are estimated by the difference between the cellulose and pentosans and total marc, after correcting for the slight quantities of ash and albuminoid matter.

*Malic and Acetic Acids.*—No attempt was made by the writer to separate the various fruit acids in the analyses previously tabulated The free acid was determined in every case by titration with decinormal soda, and calculated to malic acid. Besides the free organic acid, a considerable amount of the fruit acids exists in a combined form; the amount of this can be estimated from the alkalinity of the ash. In case of ciders and vinegars, where acetic acid is present, the latter is first removed by steam distillation and determined by titration with decinormal soda solution; the distillation should be continued until 50 cc. of the distillate shows a neutral reaction. The solution left in the flask after the steam distillation is then titrated and calculated to malic acid as before.

Pectin.—This was determined by evaporating a definite amount of the fruit extract, juice, etc., to a small volume and precipitating with a large excess of 95 per cent. alcohol. After standing over night the precipitate was collected in a Gooch crucible, and washed with alcohol to remove all sugar. The precipitate was then dried at 100° C. to constant weight, and after incineration the weight of ash deducted and the loss estimated as pectin.

Other ingredients given in the preceding tables, such as fat, protein, etc., were determined according to the official methods of the agricultural chemists, and require no special description.

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[*] For a full description of the phloroglucin method for pentosans see Bull. No. 46, Revised Edit., U. S. Dept. of Agr., Div. of Chem., p. 25.

[†] Cross & Bevan, Cellulose, p. 95.

[‡] See article by Sherman, *Jour. Amer. Chem. Soc.*, XIX, p. 306.

# VARIETY TESTS OF WHEAT.

By George C. Watson and Enos H. Hess.

## SUMMARY.

1. The yield of grain from the different varieties of wheat varied greatly, which may be accounted for in part through the difference of injury by the Hessian fly.

2. In general, the smooth chaff varieties were injured more by the fly than the bearded chaff varieties.

3. The yield of grain and straw and weight per bushel were heaviest for the bearded varieties.

4. The late sown wheat was less injured by the Hessian fly than the early sown.

## DETAILS OF THE TEST.

The primary object of these trials has been to determine, if possible, whether some of the many varieties of grain grown by farmers throughout the State are superior to other varieties in productiveness. It is well known that certain varieties in the hands of skillful men have given unusually large returns, but just how much of this increased yield is due to the superior variety in question, and how much to superior culture, fertilization, etc., is a matter of conjecture.

In these trials, the aim has been to give the different varieties uniform conditions of culture, amount of seed per acre, fertilizers, etc. This method should give fairly accurate data for comparing the productiveness of the various varieties under consideration. In addition to this, an effort has been made to test new varieties as they are introduced by seedsmen, oftentimes with flaring announcements that are more or less deceptive. While the facilities of the Station have made it impossible to test all the new varieties that are introduced from year to year, some of the more prominent and promising ones have been placed in the list and given the same treatment that the older and tried varieties have received. A somewhat similar report has been made for previous years in the annual reports and bulletins of the Station to which reference may be had.

## PLOTS.

The plots devoted to this work were .0338 of an acre in size, 134 feet long and 11 feet wide, located side by side on adjoining sloping land, inclined toward the southeast.

While these varieties were grown in plots, the objections which are oftentimes made to plot culture could hardly apply in this case, since the culture given to them was such as would be given to a field in a regular four years' rotation.

## CONDITION OF SOIL.

The soil upon which these experiments have been conducted is a limestone clay loam of about eight inches in depth, through which more or less fragments of flint are scattered. It has good natural underdrainage and contains a fair supply of organic matter. The soil is fairly uniform in fertility and depth, but the depth of the sub-soil varies greatly. In fertility, the soil is without doubt somewhat above that of the average of the State.

The rotation followed is wheat, clover, potatoes and oats. The preparation of the soil, manuring, seeding, culture and harvesting have been as nearly similar for all the plots of the different crops as possible.

For the crop of 1900 the land was plowed August 7th, 1899, about seven inches deep, and cultivated at intervals until time of sowing. About thirty-six pounds of phosphoric acid, in the form of dissolved South Carolina rock, were applied per acre at the time of seeding, and seven tons of barn manure as a top dressing before cultivation. All the varieties were sown at the rate of six pecks per acre, on September 1st, at which time the land was in good tilth. The yields reported below are from careful weighings of the product of the different plots at the time of threshing.

General View.—Experiment Station Farm.

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## *Table I.---Yield of Wheat---Varieties Tested in 1900.*

| Number. | Name of Variety. | Grain per acre, bush. 60 lbs. | Straw per acre, lbs. | Weight per struck bushel, lbs. | Per cent. of perfect stand. | Amount broken down. | Bearded or smooth chaff. | Color of grain—red, white or amber. |
|---|---|---|---|---|---|---|---|---|
| 1 | Reliable, | 22.29 | 2,505 | 64.06 | 59 | 10 | B | R |
| 2 | Dawson's Golden Chaff, | 17.64 | 1,439 | 59.69 | 61 | 10 | S | A |
| 3 | Dietz Longberry Red, | 16.92 | 2,206 | 61.81 | 59 | 11 | B | R |
| 4 | Fulcaster, | 16.91 | 2,355 | 61.22 | 56 | 15 | B | R |
| 5 | Early Genesee Giant, | 16.44 | 1,437 | 61.16 | 58 | 20 | B | A |
| 6 | Butler Co. Wheat, | 16.12 | 1,323 | 60.20 | 63 | 20 | B | R |
| 7 | Harvest King, | 15.88 | 1,574 | 62.41 | 60 | 8 | S | R |
| 8 | Harvest Queen, | 15.27 | 1,035 | 59.87 | 58 | 23 | S | A |
| 9 | Miller's Pride, | 14.81 | 1,683 | 62.14 | 60 | 9 | B | A |
| 10 | Cap Sheap, | 14.23 | 1,334 | 60.12 | 58 | 13 | B | A |
| 11 | Ontario Wonder, | 13.78 | 1,789 | 62.45 | 53 | 18 | S | A |
| 12 | Forty-Fold or Gold Coin, | 13.68 | 1,292 | 57.38 | 55 | 15 | S | W |
| 13 | Fultz, | 13.47 | 1,364 | 59.74 | 58 | 20 | S | R |
| 14 | Royal Red Clawson, | 13.04 | 1,139 | 61.61 | 63 | 10 | S | R |
| 15 | Rochester Red, | 12.70 | 1,218 | 59.58 | 60 | 15 | S | A |
| 16 | Bearded Winter Fife, | 10.92 | 1,207 | 59.52 | 45 | 23 | B | A |
| 17 | Diamond Grit, | 10.50 | 1,218 | 61.90 | 50 | 10 | B | R |
| 18 | Century, | 10.47 | 983 | 56.78 | 55 | 13 | S | A |
| 19 | Diamond White, | 10.28 | 1,127 | 58.52 | 50 | 15 | B | W |
| 20 | Early Arcadian, | 10.15 | 1,017 | 59.20 | 50 | 14 | S | W |
| 21 | Turkish Red, | 9.16 | 781 | 60.66 | 45 | 25 | B | R |
| 22 | Beechwood Hybrid, | 7.60 | 1,397 | 63.88 | 63 | 18 | S | R |
| 23 | Fultzo-Mediterranean, | 5.94 | 915 | 59.21 | 35 | 18 | S | R |
|  | Average of 23 varieties, | 13.40 | 1,406 | 60.57 | 55 | 15 | ........ | ........ |
|  | Average of 11 bearded varieties, | 14.42 | 1,561 | 61.08 | 55 | 15 | ........ | ........ |
|  | Average of 12 smooth varieties, | 12.47 | 1,264 | 60.15 | 55 | 15 | ........ | ........ |

The varieties all came up well and were looking thrifty until the latter part of September when the injury due to the Hessian fly became apparent. Ten to twenty per cent. of the plants were affected. In some instances six or seven larvae were found on one plant. The varieties all looked fairly well at the close of winter except that the outer leaves were considerably frozen. During April, the varieties did not improve in appearance but apparently became thinner, which was undoubtedly caused by the fly. The stand was scored on April 27, on the basis of 100 for perfection. As seen by the above table, the average was only 55 per cent. By June 1, the heads were nearly all out and some were beginning to bloom. As the season continued the stalks began to fall down. At the time the wheat was maturing 10 to 25 per cent. had fallen. The stalks that were not broken down had fairly well filled heads. The varieties were all cut July 6-7 and threshed July 13-14.

As will be noticed in the above table, the average yield was very low (13.40 bus.), the poorest crop produced on the Station farm since the establishment of the Experiment Station in 1887. Although the crop is quite unsatisfactory as a whole, there is considerable difference between the different varieties, the best variety, "Reliable," yielding nearly four times as much as the poorest, "Fultzo-Mediterranean." The "Reliable" has been in the lead for the last six years and judging from reports received from farmers in other parts of the State, that have been sowing this variety, it is very well adapted to limestone clay soils. The second best, "Dawson's Golden Chaff," is also a promising variety and is largely grown in Canada. The grain is light amber in color, which makes it somewhat objectionable to millers, but in hardness it is at least medium. By comparing the bearded with the smooth chaff varieties it is seen that the former gave a greater yield of grain per acre by 1.95 bushels; a greater yield of straw per acre by 297 pounds and the bearded exceeded the beardless in weight per bushel by .88 of a pound.

The somewhat general belief that smooth chaff varieties are attacked more by fly than bearded chaff varieties seems warranted by the above results. It should be observed, however, that the second best is a smooth chaff variety. This may show that the individuality of the variety is of considerable importance.

A far safer measure of the value of the different varieties is found in the following table, which gives the average results for a series of years.

*Table II.---Average Yield of Wheat Varieties for all the Years Tested.*

| Number. | Name of Variety. | Grain per acre, bush. 60 lbs. | Straw per acre, lbs. | Weight per struck bushel, lbs. | Bearded or smooth chaff. | Color of grain—red, white or amber. |
|---|---|---|---|---|---|---|
| | **1890-1900. Average 11 Years.** | | | | | |
| 1 | Reliable, | 30.97 | 3,775 | 62.81 | B | R |
| 2 | Fulcaster, | 30.42 | 4,016 | 62.81 | B | R |
| 3 | Ontario Wonder, | 29.43 | 3,150 | 62.00 | S | A |
| 4 | Dietz Longberry Red, | 28.68 | 3,628 | 62.57 | B | R |
| 5 | Fultz, | 27.06 | 3,152 | 62.27 | S | R |
| | **1896-1900. Average 5 Years.** | | | | | |
| | Reliable, | 27.82 | 3,160 | 63.13 | ....... | ....... |
| 1 | Forty-Fold or Gold Coin, | 28.27 | 2,608 | 60.39 | S | W |
| 2 | Rochester Red, | 26.22 | 2,621 | 60.89 | S | A |
| | **1897-1900. Average 4 years.** | | | | | |
| | Reliable, | 28.79 | 3,735 | 62.78 | ....... | ....... |
| 1 | Dawson's Golden Chaff, | 29.60 | 2,826 | 59.86 | S | A |
| | **1898-1900. Average 3 Years.** | | | | | |
| | Reliable, | 26.35 | 3,362 | 62.78 | ....... | ....... |
| 1 | Royal Red Clawson, | 25.00 | 2,897 | 61.59 | S | R |
| 2 | Miller's Pride, | 22.84 | 3,381 | 61.92 | B | R |
| 3 | Century, | 22.64 | 2,999 | 58.70 | S | A |
| 4 | Diamond Grit, | 20.90 | 2,987 | 62.16 | B | R |
| 5 | Diamond White, | 20.78 | 3,058 | 60.11 | B | W |
| 6 | Early Genesee Giant, | 20.60 | 2,749 | 61.24 | B | A |
| 7 | Butler Co. Wheat, | 20.26 | 1,888 | 60.59 | B | R |
| 8 | Cap Sheaf, | 19.83 | 1,793 | 60.24 | B | A |
| 9 | Bearded Winter Fife, | 19.46 | 2,728 | 60.55 | B | A |
| 10 | Early Arcadian, | 19.40 | 2,747 | 58.49 | S | W |
| | **1899-1900. Average 2 Years.** | | | | | |
| | Reliable, | 23.72 | 2,771 | 63.32 | ....... | ....... |
| 1 | Harvest Queen, | 18.44 | 1,587 | 60.28 | S | A |
| 2 | Harvest King, | 18.30 | 1,939 | 63.02 | S | R |
| 3 | Turkish Red, | 12.27 | 1,186 | 62.40 | B | R |
| 4 | Fultzo-Mediterranean, | 11.80 | 1,480 | 60.42 | S | R |

In the above table the yield for the Reliable variety is given in each group of varieties to cover the same years in order to afford a better means of comparison. Of the varieties tested eleven years the Reliable is the best although there is very little difference between it and the Fulcaster. For a period of five years Forty-fold produced .45 of a bushel more than the Reliable but 552 pounds less straw. The Forty-fold is rather soft in the grain and is objected to by many millers.

Dawson's Golden Chaff produced .81 of a bushel more grain than the Reliable as an average for four years, but 909 pounds less straw; the weight per bushel was also 2.92 pounds less. Of the varieties tested three years none produced as much grain as the Reliable but the Royal Red Clawson promises well. The grain has a smooth surface and is a little lighter than the Fultz in color. Those desiring a substitute for the Fultz could probably find it in this variety. The Fultzo-Mediterranean, a hybrid of two standard varieties does not appear to be adapted to our soil. It was badly winter killed and suffered more from the fly than most of the other varieties.

### EARLY AND LATE SOWING.

During the last decade considerable injury has been done by the Hessian fly and much has been written concerning the time of sowing as affecting the ravages of this pest. In order to test the matter, plots were sown at different dates the past two years as follows:

#### 1899.

The Reliable, a bearded variety, was sown at the rate of six pecks per acre on September 2 and 23, 1898. The winter set in earlier than usual, so that the late sown plots did not have an opportunity to tiller in the fall. There was considerable difference in the growth throughout the entire season. The plot sown September 2 matured July 3 and the one sown September 23 matured July 10. Both varieties were hauled to the barn, weighed and threshed July 12. The yield was as follows:

| | Grain per acre. bus. 60 lbs. | Straw per acre., lbs. | Weight per bushel. | Per cent. perfect stand. | Amount broken down |
|---|---|---|---|---|---|
| Plots sown September 2, .................... | 27.48 | 3,564 | 64.38 | 86 | 5 |
| Plots sown September 23, .................. | 23.71 | 2,454 | 62.07 | 73 | 5 |

The test this year would show decidedly in favor of the earlier sowing. On account of the early winter, beginning the last of November, the sowing was later in the growing season than the date would make it appear.

#### 1900.

The Reliable, a bearded variety, and Fultz, a smooth variety, were sown at the rate of six pecks per acre on August 31 and September 22. The land was prepared similar to that used for the variety tests. On October 2, the fly was quite abundant in the early sown plots, the late sown ones were just coming through the ground. On November 22d. many of the plants on the early sown plots were turning yellow and a few were dead. The insect was mostly in the pupa stage, there being as many as eight on one plant. The late sown plots were also badly affected but the plants had not turned yellow. The insect was largely in the larva stage.

Both the early and late plots were injured considerably by winter killing, the outer leaves being mostly killed by freezing. By June 9, most of the Hessian flies had hatched, the first ones were out about the middle of May.

The plots all matured about the same time. They were cut July 2 and hauled to the barn and threshed July 13.

The yield was as follows:

| | Grain per acre, bus. 60 lbs. | Straw per acre., lbs. | Weight per bushel. | Per cent. perfect stand. | Amount broken down |
|---|---|---|---|---|---|
| Reliable sown Aug. 31, | 15.60 | 1,225 | 64.16 | 58 | 15 |
| Fultz sown Aug. 31, | 12.31 | 1,089 | 62.77 | 53 | 18 |
| Reliable sown Sept. 22, | 21.25 | 1,566 | 62.55 | 61 | 12 |
| Fultz sown Sept. 22, | 19.01 | 1,665 | 63.57 | 61 | 15 |

The above shows, in the first place, considerable difference in favor of the late sown and second in favor of the bearded variety. It must be remembered, however, that the Reliable variety has proven considerably more productive than the Fultz in the variety tests so that part of the difference is due to the individuality of the variety.

In comparing this with last year's results, it plainly shows that the season governs largely the proper time to sow, and that no best date for sowing can be given. A field of wheat on the College farm sown the last of October was decidedly the best in this locality, and was very little affected by the fly. Ordinarily it would be entirely too late for this locality, but the weather remained quite warm until the last of December and thus allowed the wheat to make a fair growth in the fall.

# MISCELLANEOUS FORAGE CROPS.

By G. C. Watson and E. H. Hess.

## CRIMSON CLOVER.—(*Trifolium incarnatum*).

A number of tests of crimson clover have been made at this Station during the past six years. The main points studied were:

1. The proper time to sow.
2. Its value as a fodder plant.
3. Its value as a fertilizing plant.

In 1894, four plots of nearly one-twentieth acre each were sown to crimson clover—one each on May 9, July 7. 15 and 31. The stand on the plot sown May 9 was about 50 per cent. perfect; July 7, 75 per cent.; July 15, 90 per cent., and July 31, 70 per cent.

The plants on all the plots were little injured by freezing during the winter, but about one-fourth of the plants were killed by frosts occurring in the latter part of March and the earlier part of April. The plot sown July 31 did not suffer as much from the frosts as the others. Very little growth was made in the spring until the last week of April, after which the plants grew rapidly, the heads appearing about the middle of May. The plots sown May 9 and July 7 were cut May 28, at which time all the heads were out and the plants in full bloom. The stalks were 20 to 24 inches high. The remaining two plots, which were in about the same stage of ripeness, were cut on May 29, but the plants were on an average about two inches higher than the others. It was all fed to the cows in the green state and was eaten readily by all of them.

The yield of the four plots in pounds per acre is given in the following table:

| Date of Sowing. | Fresh substance. | Air-dry matter. |
|---|---|---|
| Sown May 9, | 9,860 | 2,154 |
| Sown July 7, | 16,300 | 3,562 |
| Sown July 15, | 23,654 | 5,121 |
| Sown July 31, | 14,146 | 3,063 |
| Average, | 14,990 | 3,475 |

The composition of the above sample when combined was:

| | Water. | Ash. | Protein. | Fiber. | Nitrogen free extract. | Fat. |
|---|---|---|---|---|---|---|
| Air-dry matter, .................. | 7.83 | 7.89 | 14.00 | 22.28 | 46.21 | 1.79 |

In 1895, crimson clover was sown in the corn field on July 24, August 2, 10 and 22, when the corn was showing ears and tassels, ears and tassels well out, past bloom and corn in milk stage respectively. No cultivation was given the corn immediately before or after any of the sowings, the last cultivation being on July 5. By the time the first plot was sown the ground was quite solid and crusted over, due to heavy rains. The plots sown August 10 and 22 were almost an entire failure. A considerable number of plants came up on the plots sown July 24 and August 2, especially in places where the ground was loose and moist. A large number of the plants that started were killed by the hot dry weather during August.

On December 19, the plants were green and vigorous and had made a fair growth. By April 14 about 75 per cent. of the plants were killed by freezing. On account of the poor stand the ground was plowed for oats and therefore no record of yield was obtained.

In an adjoining field one-tenth acre of corn was planted in July after wheat had been harvested. The last cultivation was given the corn August 21 and crimson clover sown broadcast on August 22. The surface of the ground was quite dry but underneath the loose surface there was more or less moisture. A rainfall of .37 of an inch on August 24 served to sprout the seed and by the 30th the plants were up nicely. The stand was almost perfect and on December 17 while the growth was not large the plants were green and thrifty. The spring freezing and thawing killed nearly all the plants, and by April 15 there were very few alive.

In 1896, four plots of one-twentieth acre each were sown, one plot on each of the following dates: May 8, July 16, August 15, and September 1. In each instance the land was thoroughly cultivated immediately before the seed was sown. The seed was covered by means of a weeder, going over the land twice. A good stand was scured on the plot sown May 8. The plants grew fairly well the first part of the season but did not attain any great height. The crop blossomed very unevenly, so that when it was cut on August

17, some was coming into bloom while some was past bloom. The plot sown July 16 came up very evenly and did fairly well through the season. It was not injured much by winter killing and came into full bloom May 27 when it was cut and fed to the cows.

The plot sown August 15 did not produce as good a stand by at least 50 per cent. as that sown July 16. Very little was winter killed. It came into bloom May 27 when it was cut.

The stand on the plot sown September 1st was very good, but little growth was made during the fall. Practically all the plants were winter killed and the ground was therefore used for other purposes.

The yield in pounds per acre is shown below:

| Date of Sowing. | Fresh substance. | Air-dry matter. |
|---|---|---|
| May 8, | 9,092 | 2,637 |
| July 16, | 22,849 | 3,601 |
| Aug. 15, | 7,298 | 982 |

A complete fertilizer analysis was made of each plot by Mr. W. S. Sweetser. The samples for analysis were taken from areas, four feet square. The roots were also taken from a space four feet square and two feet deep, weighed and analyzed. The results given below were reported in the Annual Report of the Station for 1897, pp. 120-133.

| Date of Sowing. | Water. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|
| Stalks: | | | | | | | |
| May 8, | 72.76 | 2.90 | 24.34 | .661 | .166 | .589 | .534 |
| July 16, | 85.57 | 1.23 | 13.20 | .391 | .065 | .363 | .282 |
| August 15, | 87.77 | 1.09 | 11.14 | .312 | .074 | .262 | .272 |
| Roots: | | | | | | | |
| May 8, | 81.98 | 3.71 | 14.31 | .282 | .080 | .206 | .211 |
| July 16, | 82.15 | 2.33 | 15.52 | .343 | .061 | .357 | .239 |
| Aug. 15, | 59.36 | 5.02 | 35.62 | .689 | .139 | .591 | .747 |

### *Fertilizer Analysis Water-free Substance.*

| Date of Sowing. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|
| **Stalks:** | | | | | | |
| May 8, | 10.65 | 89.35 | 2.427 | .609 | 2.163 | 1.960 |
| July 16, | 8.53 | 91.47 | 2.709 | .589 | 2.516 | 1.954 |
| Aug. 15, | 8.91 | 91.09 | 2.551 | .605 | 2.142 | 2.224 |
| Average, | 9.36 | 90.64 | 2.562 | .601 | 2.273 | 2.046 |
| **Roots:** | | | | | | |
| May 8, | 20.59 | 79.41 | 1.565 | .444 | 1.143 | 1.171 |
| July 16, | 13.05 | 86.95 | 1.922 | .342 | 2.000 | 1.839 |
| August 15, | 12.35 | 87.65 | 1.698 | .342 | 1.454 | 1.338 |
| Average, | 15.33 | 84.67 | 1.728 | .376 | 1.532 | 1.449 |

The estimated fertilizing material in pounds per acre is shown in the following table. The results obtained have been calculated from the weight of stalks and roots from an area four feet square.

| Date of Sowing. | Total yield. | Dry matter | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|---|
| Stalks, May 8, | 12,492 | 3,402 | 263 | 3,039 | 82.6 | 20.7 | 73.6 | 66.7 |
| Roots, May 8, | 5,964 | 1,075 | 221 | 854 | 16.8 | 2.8 | 12.3 | 12.6 |
| Total, | 18,456 | 4,477 | 584 | 3,893 | 99.4 | 25.5 | 85.9 | 79.3 |
| Stalks, July 16, | 33,900 | 4,893 | 417 | 4,476 | 132.5 | 28.8 | 123.1 | 95.6 |
| Roots, July 16, | 9,000 | 1,606 | 210 | 1,396 | 30.9 | 5.5 | 32.2 | 21.5 |
| Total, | 42,900 | 6,499 | 627 | 5,872 | 163.4 | 34.3 | 155.3 | 117.1 |
| Stalks, August 15, | 13,320 | 1,629 | 145 | 1,484 | 41.6 | 9.9 | 34.9 | 36.2 |
| Roots, August 15, | 2,970 | 1,207 | 149 | 1,058 | 20.5 | 4.1 | 17.6 | 23.2 |
| Total, | 16,290 | 2,836 | 294 | 2,542 | 62.1 | 14.0 | 52.5 | 58.4 |

It will be observed that the fertilizing material in the roots is very much less than that in the stalks, but the method used in securing the roots—passing the dry soil through a fine sieve—should be borne in mind, as this would undoubtedly leave a considerable amount of the rootlets in the soil.

In 1897, plots containing one-twentieth acre were sown July 14, August 16 and September 4, respectively. The land was plowed in the spring and cultivated occasionally to keep free from weeds. It was thoroughly cultivated at the time of sowing clover. The seed was sown at the rate of 20 pounds per acre and covered with a Breed's weeder.

There was about 75 per cent. of a perfect stand secured in the plot sown July 14 and very little was winter killed. It was cut May 31, when past bloom, the stalks being 22 to 26 inches high. The cows ate it quite readily and seemed to relish it. The yield in pounds per acre was:

| | Fresh substance. | Air-dry matter. | Per cent. moisture. |
|---|---|---|---|
| Clover, | 23,200 | 4,113 | 82.27 |

On the plot sown August 16, 25 per cent. of a perfect stand was secured, but most of the plants were winter killed. The plot sown September 4 had only one per cent of a stand and the ground was therefore used for other purposes.

In 1898, plots were sown July 15, August 15 and September 1. The ground was prepared and the seed sown in the same way as in 1897. The stand secured by the different sowings was:

| | |
|---|---|
| July 15, | 18 per cent. |
| August 15, | 20 per cent. |
| September 1, | 10 per cent. |

The clover on the plot sown September 1 was nearly all killed by the winter freezing. On the other two plots many of the plants were heaved out an inch or two and the top leaves were nearly all killed by freezing.

In 1899, plots were sown July 15, August 16 and September 1 on ground prepared in the same way as that described in the two previous seasons. Estimating a perfect stand as 100 the stand of clover secured by the different seedings was estimated to be as follows:

| Date of Sowing. | Per cent. of perfect stand. |
|---|---|
| July 15, | 50 |
| August 16, | 2 |
| September 1, | 1 |

The first plot had about 40 per cent. of the plants winter killed, leaving 30 per cent. of a perfect stand, while the plants on the other two plots were practically all killed.

## CONCLUSIONS.

1. Crimson clover will mature seed in one season if sown in the fore part of May.
2. Crimson clover sown during July has given larger yields than August or September sowing.
3. It is important to have a good mellow seed bed and have the seeds well covered to secure a good stand.
4. The stand secured depends very much upon the weather conditions at the time of sowing the seed.
5. The greatest injury was caused by freezing and thawing in the early spring.
6. Strong vigorous plants of early seeding withstood the freezing much better than the weaker plants of late seeding.

## CANADA FIELD PEAS.

The value of the Canada field pea as a forage crop has been recognized for a number of years by farmers, especially in Canada and in the States bordering on the Great Lakes, where it is grown both as a forage and a grain crop. The yields obtained by the trials made at this Station are reported below.

In 1894 seven plots of one-twentieth acre each were grown to peas and seven to peas and oats. The land was plowed about seven inches deep and cultivated April 16. On April 17 Canada field peas were sown four inches deep on all the plots at the rate of two and one-half bushels per acre. On each alternate plot oats were sown at the usual depth at the rate of one and one-half bushels per acre. 240 pounds of dissolved South Carolina rock were applied per acre to all of the plots. Both the peas and oats made a good growth. Where sown alone the peas fell down and were difficult to cut. The oats were past the milk stage when cut and the peas had well formed pods, a few having matured. The plots were cut July 7 to 12, the yield being as follows:

### *Peas and Oats.*

| Date of Cutting. | No. of plot. | Fresh substance per acre in lbs. | Air-dry matter per acre. |
|---|---|---|---|
| July 7, | 1 | 12,800 | 3,963 |
| July 7, | 3 | 10,600 | 3,286 |
| July 9, | 5 | 10,850 | 3,572 |
| July 10, | 7 | 11,800 | 3,940 |
| July 11, | 9 | 10,300 | 4,162 |
| July 12, | 11 | 10,100 | 4,098 |
| July 12, | 13 | 8,000 | 3,232 |
| Average, | ...... | 10,636 | 3,751 |

### *Peas.*

| | | | |
|---|---|---|---|
| July 7, | 2 | 10,400 | 2,580 |
| July 7, | 4 | 9,600 | 2,380 |
| July 9, | 6 | 8,600 | 2,178 |
| July 10, | 8 | 8,200 | 2,288 |
| July 11, | 10 | 8,800 | 4,014 |
| July 12, | 12 | 4,700 | 2,144 |
| Average, | ...... | 8,383 | 2,597 |

By the above it is seen that considerably the largest yield was obtained with peas and oats grown together. Assuming the yield of peas and oats to be one hundred, the yield of peas is 78.82 for the fresh and 69.13 for the air-dry matter. The pea plots were badly lodged and tangled, making it quite difficult to cut, while the peas and oats stood erect and could be cut readily with a machine. In either case the yield compares favorably with an average hay crop and can be made to serve a valuable purpose in supplying food for dairy cows.

In 1895 a plot containing one-twentieth of an acre was sown to peas and oats May 21. The peas were sown four inches deep at the rate of three bushels per acre and the oats at the rate of six pecks per acre. In order to get the peas down deep enough, a narrow board was placed on back of hoes upon which a man placed part of his weight. By May 31 the oats were well up and the peas were coming up. Both the peas and oats made a good growth, each being about twenty-four inches high. The plot was cut July 23, at which time the peas were in bloom and the oats were in the milk stage. The cows ate the oats very readily but left some of the pea vines. The yield per acre was:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| Peas and oats, | 17,600 lbs. | 3,450 lbs. |

The yield of air-dry matter is nearly the same as the average of the plots last year, namely, 3,751 lbs per acre.

In 1896 a plot containing one-twentieth of an acre was sown to Canada field peas on April 30 at the rate of six pecks per acre. The plants appeared May 10, began to bloom July 1, and were in full bloom July 7. The plot was cut July 30, some of the pods being yellow and nearly ready to open. The cattle ate the green tops up clean except portions of the stems which had rotted from the wet weather. The yield per acre was:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| Canada field peas, | 14,148 lbs. | 2,999 lbs. |

A complete fertilizer analysis was made of the stalks and roots by Mr. W. S. Sweetser. The roots were taken from a space four feet square and two feet deep by means of sifting the soil through a fine sieve. The results given below were reported in the Annual Report of the Station for 1897, pp. 120-133.

*Fertilizer Analysis of Fresh Substances.*

| | Total moisture. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|
| Stalks, | 80.45 | 2.82 | 16.73 | .536 | .141 | .257 | .346 |
| Roots, | 80.53 | 3.29 | 16.18 | .455 | .132 | .155 | .238 |

*Fertilizer Analysis Water-free Substances.*

| | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|
| Stalks, | 14.42 | 85.58 | 2.742 | .721 | 1.315 | 1.770 |
| Roots, | 16.90 | 83.10 | 2.336 | .677 | .796 | 1.171 |

The fertilizing material per acre of the whole crop as calculated from sixteen square feet of surface is shown in the following table:

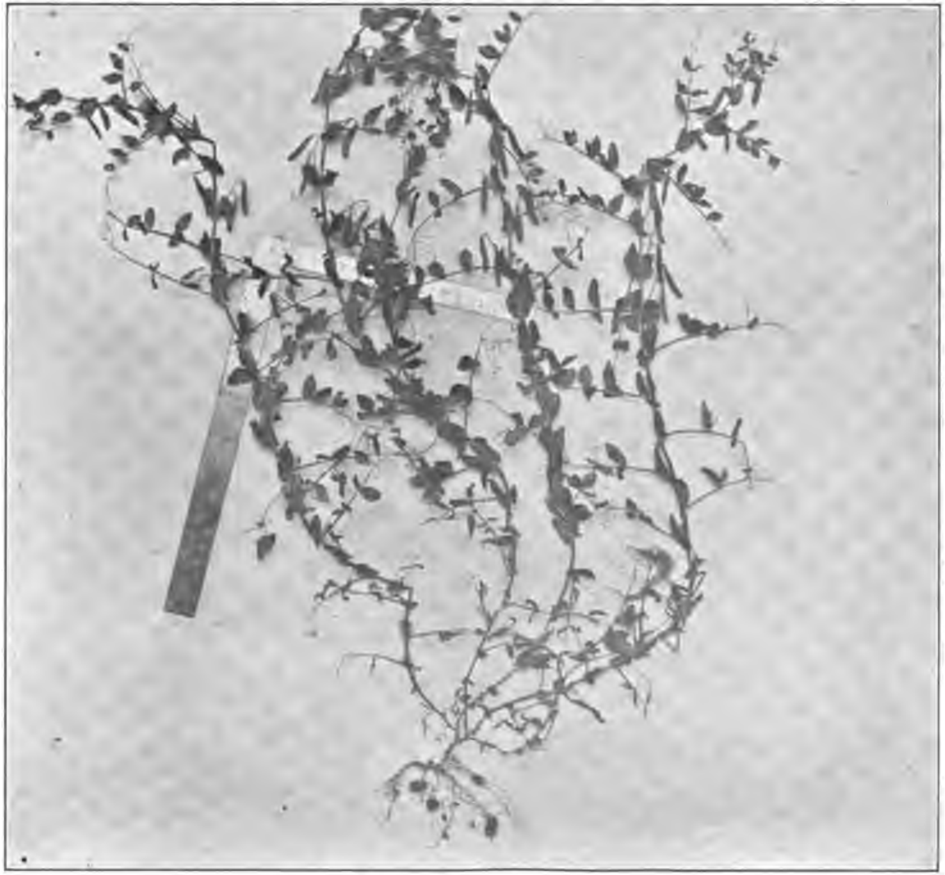
*Stalks.*

| | Total yield. | Dry matter. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|---|
| Stalks, | 20,142 | 3,937 | 568 | 3,369 | 108.0 | 28.4 | 51.8 | 69.7 |
| Roots, | 1,440 | 281 | 47 | 234 | 6.6 | 1.9 | 2.2 | 3.4 |
| Total, | 21,582 | 4,218 | 615 | 3,603 | 114.6 | 30.3 | 54.0 | 73.1 |

The fertilizing matter in the roots is very much less than that in the stalks, but the method used in securing the roots—passing the dry soil through a fine sieve—would undoubtedly leave a considerable proportion of the rootlets in the soil. The development of nodules on the roots is shown in the accompanying cuts.

It would be necessary to apply 716.3 pounds nitrate of soda to an acre to equal in pounds the amount of nitrogen in the total crop, stems and roots. From a large number of experiments conducted with garden peas at the Storrs' School Agricultural Experiment Station 33.39 per cent. of the total nitrogen in the plants was acquired from the atmosphere. On this basis, the Canada field pea plowed down would have enriched the soil in nitrogen by 38.26 lbs. per acre, or an equivalent in weight of nitrogen of 239 lbs. nitrate of soda, which under ordinary conditions would be considered a heavy application.

In 1897 a plot of Canada field peas was sown at the rate of two bushels per acre. The plot was cut August 4, when the majority of



CANADA FIELD PEA VINE—Showing Roots and Clusters of Nodules.

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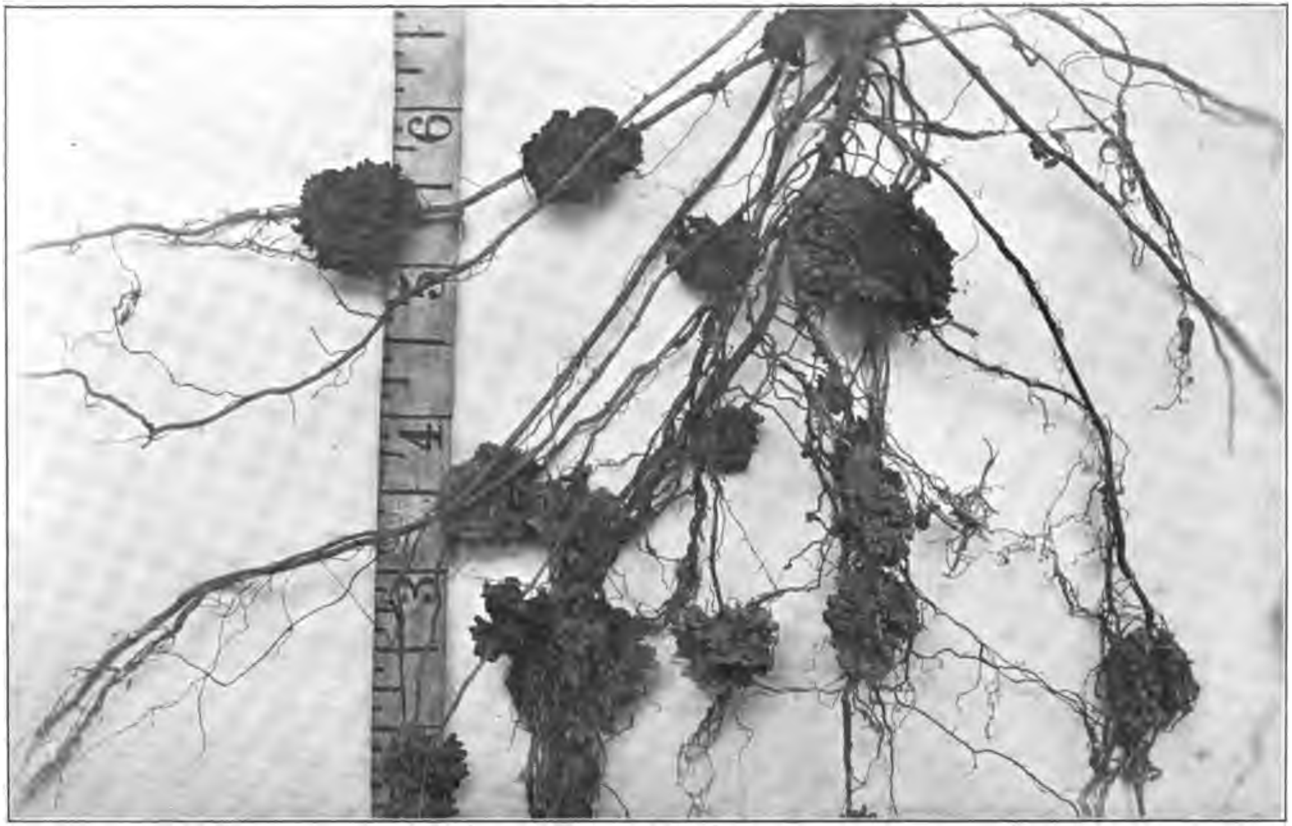


Roots of Canada Field Pea—Showing Clusters of Nodules.

the peas were in the dough stage, a few being hardened. The following is the yield per acre:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| Canada field peas, | 9,650 lbs. | 3,016 lbs. |

The cows ate the vines readily, but the amount was not large enough to make a careful test of their feeding value, as compared with other forage crops.

In addition to the above, one plot each was sown to oats, oats and barley, barley, peas, and peas and oats. The land was plowed 7 to 8 inches deep May 1 and thoroughly cultivated with spring and spike tooth harrows, after which the seed was sown as follows:

Plot I.—Sown with oats at the rate of two bushels per acre.

Plot II.—Sown with oats and barley mixed (equal parts by measure), at the rate of two bushels per acre.

Plot III.—Sown with barley at the rate of two bushels per acre.

Plot IV.—Sown with peas, at the rate of two bushels per acre.

Plot V.—Sown with oats and peas (mixed equal parts by measure) at the rate of two bushels per acre. The yield of the different plots in pounds was:

| Plot. | Date of harvesting. | Fresh substance. | Air-dry matter. |
|---|---|---|---|
| I, | July 17, | 10,006 | 3,774 |
| II, | July 14, | 9,543 | 4,232 |
| III, | July 14, | 9,343 | 4,509 |
| IV, | July 15, | 8,943 | 2,339 |
| V, | July 15, | 10,314 | 3,187 |

The oats when cut were in the milk stage, the barley and peas were in the dough stage, a few of the grains beginning to harden. The forage was fed to the cows in the fresh state and was eaten quite readily except in the case of the more fully matured barley and pea stalks.

As in former years, the trial shows that the greatest amount of forage can be produced where the peas are sown with some other crop.

In 1898 a Russian variety of field peas was compared with Canada field peas. The stand secured was poor in both cases, especially with the Russian variety. The nature and growth of the Russian variety resembled very much the Canada field pea and matured at the same time. No superiority over the old variety could be noticed. In fact, the yield was considerably less, but as the stand was so poor it could not be considered a fair test.

## CONCLUSIONS.

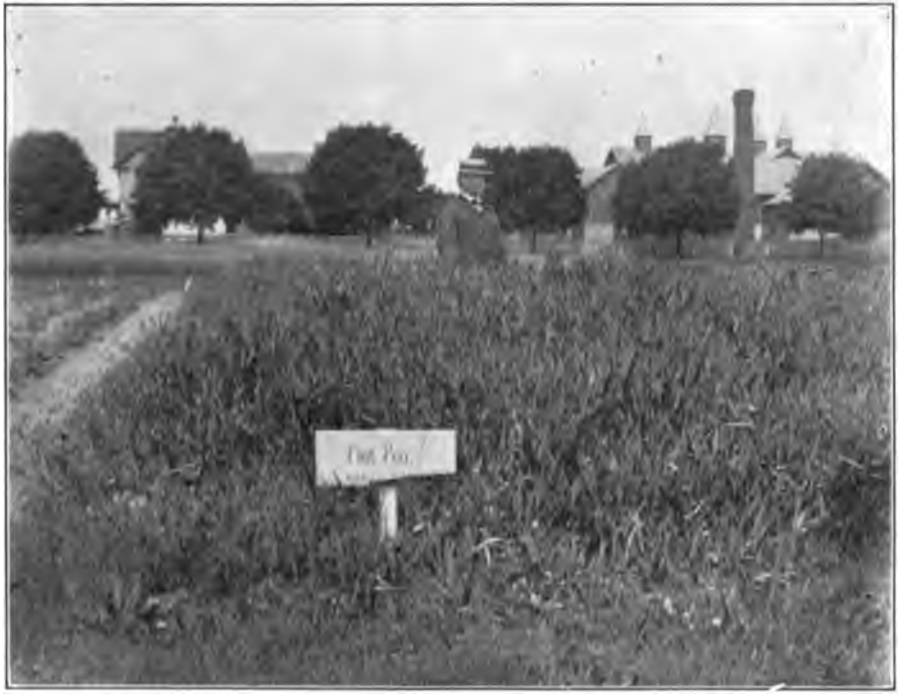
1. The Canada field pea is valuable both as a forage and renovating crop. As much forage can be raised as with a good hay crop.
2. The greatest amount of forage is secured when the peas are sown with oats, and are much more easily harvested than when sown alone.
3. A bushel and a half to two bushels of peas with a bushel to a bushel and a half of oats is the proper amount of seed to use. The peas should be covered three or four inches deep and sown as early in the spring as the ground will permit. The oats should not be covered more than two inches deep and may be sown at same time as peas, or five to six days later.
4. Peas, when cured, are not relished as much by cattle as good clover hay, but are eaten quite readily. In no instance have cattle refused to eat them when in the green stage.

## FLAT PEA.

This pea has attracted considerable attention during the last ten years, and is fully described by F. Lamson-Scribner in Circular No. 11, Division of Agrostology, United States Department of Agriculture, Washington, D. C., to which reference may be had for fuller information. Quoting in brief: "The flat pea is a variety of the woodland pea (Lathyrus sylvestris) which is not very different in appearance from the common, or everlasting, pea. It is a perennial, enduring sometimes for twenty-five years or more, has strong, deep, much-branched roots, and produces many trailing or climbing stems, which interlace in great tangled masses." * * * * *

This pea is a native of Europe, and is most abundant in the Central Southern parts, extending into Northern Africa. It is found in thickets and hedge rows and on rocky hillsides, blossoming throughout the summer."

It is very deep-rooted and withstands drouth very well, remaining green when all other herbage would be practically burned up. "Owing to its power of taking nitrogen from the air, and therefore of growing without the aid of nitrogenous manures when once well established, the flat pea is thought to be especially adapted to comparatively poor, sandy, shaly, or 'chalky' soils. * * * * * * The Lathyrus is said to be a good binder for drifting, sandy soils,



**Flat Pea.**—Lathyrus Sylvestris.

the strong, deeply penetrating roots forming a mesh which holds the particles of soil together. The roots are sometimes 20 to 30 feet long." "It is claimed that the hay of the Wagner flat pea makes an excellent fodder, much relished by cattle, sheep and hogs, and contains more nutriment than most standard fodders."

## RESULTS OBTAINED AT THIS STATION.

A small plot of ground was planted May 9, 1894. The seed was placed four to six inches apart in rows thirty-six inches apart and covered about four inches deep. The plants had not come up by July 7, and thinking that the seed was poor the ground was cultivated and a plot containing one-fortieth of an acre replanted. The last planting came up rather irregular and made a poor growth. In 1895 the plot was kept reasonably free from weeds by surface cultivation and new seed put in the missing places. The growth was not large enough to cut and it appeared as though the plant would be a failure.

In 1896 the plot was cultivated and kept free from weeds. The plants made a good growth, especially on the damper parts of the plot. By July 8th, the growth was about two feet high, the vines being much interwoven. There were quite a number of flowers on the plants and some pods were formed.

The plot was cut with a scythe and fed to the cows in the green state, but was not relished by them, some refusing to eat any of it. After cutting, the plot soon began to make a second growth which was cut October 16. The yield per acre in pounds was:

| Date of Cutting. | Fresh substance. | Air-dry substance. |
|---|---|---|
| July 8, | 12,786 | 3,127 |
| October 16, | 6,252 | 2,001 |
| Total, | 19,038 | 5,128 |

A complete fertilizer analysis was made of that harvested July 8, by Mr. W. S. Sweetser. The roots were also taken from a space four feet square and two feet deep, weighed and analyzed. The results given below were reported in the Annual Report of the Station for 1897, pp. 120-133.

### *Fertilizer Analysis.*

| | Water. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|
| **Stalks:** | | | | | | | |
| **Fresh substance,** | 77.72 | 1.94 | 20.34 | .682 | .140 | .457 | .357 |
| **Water-free substance,** | ........ | 8.71 | 91.29 | 3.06 | .628 | 2,051 | 1,602 |
| **Roots:** | | | | | | | |
| **Fresh substance,** | 78.69 | 2.58 | 18.73 | .410 | .088 | .281 | .195 |
| **Water-free substance,** | ........ | 12.11 | 87 89 | 1.924 | .413 | 1.319 | .915 |

The following table gives the estimated weight of stalks and roots per acre and also the fertilizing material which they contain. The estimation is based on the yield of an area four feet square as previously described.

### *Pounds Per Acre.*

| | Total yield. | Dry matter. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|---|
| **Stalks,** | 25,560 | 5,696 | 497 | 5,199 | 174.3 | 35.8 | 116.8 | 91.3 |
| **Roots,** | 15,852 | 3,377 | 409 | 2,968 | 65.0 | 14.0 | 44.5 | 30.9 |
| **Total,** | 41,412 | 9,073 | 906 | 8,167 | 239.3 | 49.8 | 161.3 | 122.2 |

The above table shows that the plant contains a large amount of fertilizing materials and should be an excellent crop for renovating wornout land. The roots were very large and went down considerably deeper than the two feet, the lowest depth of sampling, so that the weights for the roots are evidently too small. Again, it was impossible to get all the small roots out of the soil by the method used—passing the soil through a fine sieve. To supply the amount of nitrogen found in the crop in nitrate of soda, it would require 1,089.4 pounds for the stalks, 406.3 pounds for the roots, or a total of 1,495.7 pounds nitrate of soda per acre.

There was a very large number of nodules on the roots of this crop, many of them gathered into quite large clusters. This may account, in part, for the large amount of nitrogen in the crop.

A comparison of the fodder analysis with that obtained at other Stations is shown below.

| | Pennsylvania Station. cut in bloom. | Michigan Station. | California Station. Cut after bloom. | England. Cut after bloom. |
|---|---|---|---|---|
| Ash, | 8.6 | 9.0 | 8.7 | 7.5 |
| Crude protein, | 25.0 | 29.5 | 22.4 | 18.0 |
| Crude fiber, | 28.6 | 29.0 | 26.7 | 29.5 |
| Notrogen-free extract, | 34.3 | 30.2 | 37.7 | 40.1 |
| Crude fat, | 3.5 | 2.3 | 4.5 | 4.9 |

In 1897 a very good growth was made, the character of which is shown in the following cut:

A part of the crop was fed in the green stage and the remainder cured as hay, before feeding. About half of the cows ate it readily, others ate the greater part, while a few ate scarcely any. It was eaten about as readily when dried as in the green state. There was no perceptible change in the milk flow but the amount was not large enough to make a careful test. The first crop was cut July 13, the second October 5. The following is the yield per acre in pounds:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| July 13, | 21,568 | 5,851 |
| August 5, | 8,067 | 3,216 |
| Total, | 29,635 | 9,067 |

The above yield is very large when compared with a good yield of clover or timothy and is, in fact, as much air-dry matter as is secured in a good corn crop.

In 1898 the first crop, cut June 16, was very heavy, but the second was very poor. For about two months after the crop was cut practically no growth was made and the plants were yellow and looked as though they were drying out. About the last week in August the plants began to turn green and made a small growth before frost, but were not harvested. The following yield in pounds per acre was secured:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| Yield in lbs. per acre, | 28,959 | 5,494 |

It was fed to the cows in the green stage. They ate it readily, except the harder parts of the stems.

Another plot was sown in the spring but the plants did not grow large enough to be cut.

In the spring of 1899 another plot containing .118 of an acre was sown. The tops of the plants that were started in 1894 were frozen and there was no apparent advantage in not cutting the second crop in the fall.

On the plot planted the previous spring a number of the plants were killed by freezing. Some were heaved out of the ground at least three inches, indicating that the soil of the Experiment Station farm holds too much moisture for the most successful cultivation of this crop. The plot was not cut until September 27. There was a fair growth on the plot by June 30, but it was not cut. In the latter part of July the plants had a yellow, unthrifty appearance. About the middle of August a second growth started and the first died off, apparently showing that the first growth should have been removed.

The plot yielded at the rate of 4,032 pounds of fresh substance per acre which contained 1,370 pounds of air-dry matter.

The yield of the plot planted in 1894 is shown below.

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| June 30, 1899, | 17,823 | 3,975 |
| September 27, 1899, | 4,840 | 1,544 |
| Total, | 22,663 | 5,519 |

When cut June 30 the plants were in bloom and some pods formed. Some were fed green and the remainder dried in the sun and then fed. In the green stage it was eaten readily by all the cows. It did not change the flow of milk as compared with green timothy; there was not enough, however, to give it a thorough trial. In the dry stage the cows ate it nearly as well as when green.

An objection to the plant is the difficulty with which it is cut.

The vines mat together very much making it necessary to cut it with a scythe or sickle. Where the growth is large, it is necessary to tear the vines apart after each row is cut. However large plots should be readily cut with a mowing machine.

Late in the fall of 1899 the plots were mulched with a heavy coat of strawy manure. This prevented considerable heaving, although some plants were killed as in the previous winter. Of the seed sown in 1899, it was observed that some did not come up until the middle of May, 1900. The seeds were sown dry.

### CONCLUSIONS.

1. To grow the crop successfully, the soil should not be wet enough to cause much heaving.
2. The seed should be scalded before planting, a satisfactory method being to pour enough boiling water over the seed to cover it and let it stand for twenty-four hours.
3. The seed should be planted in rows far enough apart to allow of horse cultivation. If the rows are not more than twenty-four or thirty-six inches apart, the plants need not be closer than six inches in the row. Thorough cultivation should be given until the plants cover the ground.
4. The flat pea promises well as a forage crop. It is not eaten readily at first, but cattle become accustomed to it and eat it with considerable relish.
5. It stands a drouth well and should do well on dry soils.
6. The large yields attest to its value as a forage crop.
7. The chief objections are:
   (a) The length of time necessary for the young plants to become well established.
   (b) It is somewhat difficult to harvest.

### VETCHES.

A plot of one-twentieth acre was sown to spring vetch April 30 at the rate of one bushel of seed per acre. The stand was fair and the plants began to bloom July 7. Soon after the plants began to bloom they were infested with blister beetles which largely prevented the formation of pods. When cut on September 23 the plants were in an unthrifty condition, there being few pods formed and the lower part of the stalks were more or less brown. The yield in pounds per acre was 3,365 for fresh substance and 2,432 for air-dry matter.

Russian vetch (Vicia villosa), also known as sand or hairy vetch. Seed of this variety was obtained from the United States Department of Agriculture and with it was received the following description: "Hairy vetch is an excellent annual soiling crop, one of the best that has been introduced into the United States, although it has not been widely cultivated. Sow one and one-half bushels per acre from the latter part of April to the middle of May for summer forage, or from the middle of August to the middle of September for winter forage. It is a fine soiling crop and green manure. The yield of hay varies from one and one-half to four tons per acre, according to the fertility of the soil. It has been grown successfully in all parts of the country and is both hardy and drought resistant. It is deserving of wider cultivation in all parts of the United States."

A plot was sown at the rate of one and one-third bushels seed per acre on September 15, 1896. A good stand was secured which came through the winter quite well. The plants were in full bloom by June 13. After this the leaves began to die at the bottom but continued growth at top. The plot was cut June 28 and fed to the cows in a green state. The yield in pounds per acre was 5,250 of fresh substance and 1,785 of air-dry matter.

Although the yield of fresh substance was considerably more there was a less yield of dry matter per acre by 647 pounds than that given by the spring vetch.

A complete fertilizer analysis was made of the stalks and roots of both varieties. The roots were taken from a space four feet square and two feet deep and were separated from the soil by passing the soil through a fine sieve. The results given below were reported in the annual report of the Station for 1897, pp. 120-133.

*Fertilizer Analysis.*

| | Water. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|
| **Spring Vetch.** | | | | | | | |
| Stalks: | | | | | | | |
| Fresh substance, | 32.82 | 6.45 | 60.73 | 1.358 | .572 | 1.503 | 1.561 |
| Water-free substance, | | 9.60 | 90.40 | 2.021 | .851 | 2.237 | 2.324 |
| Roots: | | | | | | | |
| Fresh substance, | 79.38 | 2.05 | 18.57 | .388 | .140 | .280 | .302 |
| Water-free substance, | | 9.94 | 90.06 | 1.880 | .679 | 1.358 | 1.465 |
| **Russian or Sand Vetch.** | | | | | | | |
| Stalks: | | | | | | | |
| Fresh substance, | 63.12 | 3.25 | 33.63 | 1.100 | .317 | .744 | .580 |
| Water-free substance, | | 8.81 | 91.19 | 2.983 | .860 | 2.017 | 1.573 |
| Roots: | | | | | | | |
| Fresh substance, | 85.78 | 2.06 | 12.16 | .279 | .084 | .162 | .225 |
| Water-free substance, | | 14.49 | 85.51 | 1.962 | .591 | 1.139 | 1.582 |

The following table gives the amount of fertilizing material in pounds per acre as determined from the weight of stalks and roots from areas four feet square:

| | Total yield. | Dry matter. | Ash. | Organic matter. | Nitrogen. | Phosphoric acid. | Potash. | Lime. |
|---|---|---|---|---|---|---|---|---|
| **Spring Vetch:** | | | | | | | | |
| Stalks, | 8.832 | 5,934 | 570 | 5,364 | 119.9 | 50.0 | 132.7 | 137.9 |
| Roots, | 1.906 | 393 | 39 | 354 | 7.4 | 2.7 | 5.3 | 5.8 |
| Total, | 10,740 | 6,327 | 609 | 5,718 | 127.3 | 53.2 | 138.0 | 143.7 |
| **Russian Vetch:** | | | | | | | | |
| Stalks, | 6,756 | 2,492 | 220 | 2,272 | 74.3 | 21.4 | 50.3 | 39.2 |
| Roots, | 1,560 | 231 | 32 | 189 | 4.4 | 1.3 | 2.5 | 3.5 |
| Total, | 8,316 | 2,713 | 252 | 2,461 | 78.7 | 22.7 | 52.8 | 42.7 |

From the above table it will readily be seen that the crop contains a large proportion of fertilizing ingredients and should serve a valuable purpose for renovating worn out lands, even if its feeding value is no greater than that of other popular forage crops. Many practical agriculturists believe that the roots of plants contain as much fertilizing matter as the stalks. The foregoing results, however, indicate that by far the greater part of the fertilizing constituents is contained in the stems and leaves. Without doubt many small rootlets were not removed from the soil in passing the soil through a sieve and consequently the estimated amount of the fertilizer ingredients in the roots is probably somewhat too low. While some leaves were lost yet the relative proportion of loss through the loss of leaves will probably not be so great as that through the rootlets which were not recovered.

In 1898, a plot was sown to Russian vetch and one to vetch and oats. The vetch was sown at the rate of six pecks per acre; the vetch and oats were mixed in equal parts by measure and sown at the rate of two bushels per acre. A good stand of vetch and oats was secured. The plots were cut July 15, at which time the vetch and oats were in bloom. The cows did not eat the vetch as readily as the oats. The yield of the plots in pounds per acre is shown below:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| Vetch, | 11,594 | 2,980 |
| Vetch and oats, | 10,400 | 3526 |

The vetch where sown alone lodged badly and was difficult to cut. On the other plot, the oats served as a support for the vetch. Thus both plants stood erect and were easily harvested.

By August 13, the vetch on both plots had made a fair second growth and was beginning to bloom. Both plots were cut August 30, when in full bloom. The plot sown to vetch alone in the spring had considerably more weeds than the one sown to vetch and oats, so that the actual yield of vetch of the former plot was not as much higher as would appear from the actual weights obtained. There was no second growth of oats. The yield obtained was:

| | Fresh substance. | Per cent. moisture. | Air-dry matter. |
|---|---|---|---|
| Vetch plot, | 6,500 | 80.20 | 1,287 |
| Vetch and oats plot, | 5,500 | 79.26 | 1,141 |

The following is the total yield for the first and second crops:

| | Fresh substance. | Air-dry matter. |
|---|---|---|
| Vetch, | 18,094 | 4,267 |
| Vetch and oats, | 15,900 | 4,667 |

After the second crop was cut the plants began to grow again and during the fall formed a thick mass of vines which thoroughly covered the ground. During the winter about fifty per cent. of the leaves were killed, but the plants were mostly in good condition.

The plants began to bloom May 20, and by June 8 they were in full bloom. Some of the vines began to die off at the bottom. The average height over the plot was about eighteen inches, even after the vetch had lodged a great deal. Many of the plants were three or four feet long. The plots were cut June 16, when many pods had formed and the seed was in the dough stage. The cows ate the green portions but rejected many of the stalks as they had become somewhat woody. The yield in pounds per acre was:

| | Fresh substance. |
|---|---|
| Vetch, | 12,500 |
| Vetch and oats, | 10,000 |

There was no growth made after this, the third cutting, and the plots were therefore used for other purposes.

The results obtained would indicate that Russian vetch is a valuable acquisition to our list of forage crops. On account of the difficulty in harvesting the crop when sown alone, it should be sown with oats or barley as it can then be cut with a machine. One advantage of sowing it with oats is that the two plants mature about the same time. An equal amount of vetch and oats by measure sown at the rate of one and one-half to one and three-fourths bushels per acre will give a good stand under favorable circumstances.

## SPURRY.

*Spergula arvensis.*

This plant has been highly recommended for dry sandy soils where clover and other more valuable forage crops cannot be grown. It is said to be eaten readily by horses, cattle and sheep.

On May 9, 1894, one one-twentieth acre plot was sown. The seed was sown broadcast and well harrowed in.

On June 28 the plot was cut for forage, the plants being about twelve inches high and well past bloom. Soon after cutting the plants commenced to produce a second growth which grew quite rapidly. The second crop was cut July 25 when the plants were five or six inches high. A third cutting was made September 7 when the seeds were well formed. The following table shows the total yield per acre and the yield at each cutting:

| Date of Cutting. | Weight of fresh substance. | Air-dry Matter |
|---|---|---|
| June 28, | 7,240 | 1,182 |
| July 25, | 1,680 | 610 |
| September 7, | 360 | 168 |
| Total, | 9,280 | 1,968 |

On May 9, 1895, one one-twentieth acre plot was sown at the rate of seven pounds of seed per acre. The plot was well fitted with a spring tooth harrow, the seed was sown broadcast and harrowed in. Good germination was secured but about forty per cent. of the plants were destroyed by a somewhat severe drouth which followed germination.

The plot was cut July 23, when the seeds were in the dough stage, and yielded 4,850 pounds of fresh substance, or 1,164 pounds of dry matter per acre. The second growth was so poor that no attempt was made to harvest it.

The fresh substance was readily eaten by milch cows which were being fed soiling crops.

The above records of yields do not indicate that spurry should replace the more common forage crops which are now grown on arabie soils of Pennsylvania.

## MILLET.

As letters of inquiry pertaining to millet as a forage crop for Pennsylvania are annually received at this Station, it was thought advisable to test the growth of one or more of the common varieties which are grown for forage in eastern United States.

Accordingly two plots of one-twentieth acre each were sown to Golden Wonder millet (Setaria Italica) May 21, 1895. The seed was sown by hand on well prepared land and harrowed in. The soil of these plots was limestone clay loam and naturally well drained. The seed germinated well and produced a good stand of plants uniformly over both plots. The subsequent growth was quite satisfactory. The plots were cut when the seed was in the dough stage, August 29 and September 2. The yield per acre of air-dry matter was 6,307 and 6,915 pounds, giving an average of 6,661 pounds.

The larger portion of the millet, soon after being cut, was fed and readily eaten by the cows of the Experiment Station herd which were fed with soiling crops.

The above mentioned yields would indicate that whenever an unsatisfactory stand of grass or clover is secured, millet may be used as a profitable roughage substitute on limestone clay soils.

Japanese millet (Panicum Crus-galli-major), a member of the group of millets often called "Barnyard millets," from the fact that they are derived from the common barnyard grass Panicum Cris-galli. These millets grow taller and are much coarser than the Foxtail millets, of which the German, Hungarian and Golden Wonder millets are familiar varieties.

In 1897 a plot of Japanese millet and a plot of the New Siberian millet were sown. The latter variety resembles the Hungarian millet in the form of the head while the plants are somewhat larger.

These two plots were sown broadcast and harrowed in. The seed germinated well and produced a good even stand. When the seeds were in the dough stage the plots were cut. The yield per acre is shown below:

| Variety. | Fresh substance. | Air-dry matter |
|---|---|---|
| Japanese, | 22,300 | 5,537 |
| New Siberian, | 13,728 | 4,050 |

While the above results were obtained by plot cultivation, yet the conditions were no better than would be secured in field cultivation where thorough culture is given.

These results tend to show that millets may serve a most useful purpose as a substitute whenever clover has been winter killed or the usual hay crops have become partial failures. Millet may be sown after an early hay crop when too late to safely plant corn.

The following summary is quoted from Michigan State Agricultural College Experiment Station Bulletin No. 117.

"Millet requires good soil, preferably sand, and is especially adapted to new land. Sow half a bushel per acre for hay, one peck if for seed.

Millet hay is strong feed and should be used with caution, being alternated if practicable with other fodder, especially if fed to horses. It is safer and more palatable if cut before the seed begins to ripen. The best variety is German millet, providing the soil is good and can have the entire season. For late sowing or poor soil use common millet. Hungarian grass on fertile soils in a moist season would give a large yield of excellent fodder."

### SUNFLOWER.

### *Helianthus annuus.*

In order to answer from actual trial the somewhat frequent inquiry "Can sunflowers be profitably grown in Pennsylvania?" a few plots have been planted to Russian gray and Russian white sunflowers, as described below.

The plots were one-twentieth acre in size, and were given good culture similar to that given corn under field conditions on the College and Experiment Station farms.

The seed was planted in rows three feet apart and from fourteen to twenty inches apart in the row. With the exception of the plot grown in 1899 the plants made a good growth and appeared to be of a suitable thickness for most abundant seed production. Nearly every stalk produced a good-sized head.

When ripe the heads were cut off and sun-dried on the plot for several days. Then they were removed to the barn and spread out to dry for several weeks.

| Name of Variety. | Year. | Date of planting. | Date of harvest. | Weight of grain per acre. | Weight of seed per Measured bushel. | Bushels per acre. |
|---|---|---|---|---|---|---|
| Russian Gray, | 1897 | .......... | Sept. 29 | 1,225 | 23 lbs. | 53.26 |
| Russian Gray, | 1898 | May 13 | Oct. 13 | 1,186 | 27.62 lbs. | 42.9 |
| Russian White, | 1898 | May 13 | Oct. 13 | 1,082 | 26.38 lbs. | 41.01 |
| Russian Gray, | 1899 | May 6 | ............ | 568 | ............ | ........ |

The seed was readily eaten by fowls when fed with wheat and oats. The fowls for the most part broke the hulls and ate only the kernels.

Without accrediting a much greater value to sunflower seeds as a poultry food than that recognized at the present time, it must be conceded that the cereals usually grown in Pennsylvania afford by far a much cheaper food than sunflower seeds.

# SOIL INOCULATION FOR ALFALFA.

By G. C. Watson and E. H. Hess.

Several attempts have been made to establish small plots with alfalfa on the limestone clay soil of the Experiment Station farm, but without satisfactory results. While the land is naturally well underdrained, it holds too much water of capillarity to enable the plants to withstand the freezing and thawing of the first winter after seeding.

In nearly every instance the plants made a small or moderate growth during the first growing season and were unable to endure the severity of the winter under the soil conditions of the Experiment Station farm.

Three attempts were made during three different years to obtain a stand of alfalfa but with only partial success even when the plants did the best.

In 1898, a somewhat more extended trial was made than any that had preceded. Six one-twentieth acre plots lying side by side which had previously grown red clover, white clover, alsike clover, timothy, millet and vetch respectively were plowed and laid off into three plots which extended crosswise of the former plots of clover, timothy, etc., so that each one of the three new plots contained an equal portion of each of the former plots.

The ground was plowed eight inches deep, April 15, and kept well cultivated until May 27, when the seed was sown broadcast and harrowed in.

Before seeding, about a bushel of soil was sown on plot No. 1. This soil was obtained from land which had grown good crops of alfalfa for several years on the New York State Experiment Station farm, at Geneva, New York.

The seed sown on plot No. II was treated with an artificial culture known "as "Nitragin," which was claimed to consist of a pure culture of the specific bacteria of legume nodules in a suitable medium The "Nitragin" preparation was obtained from Lucius and Brüning, Hoechst on Main, through their agents for the United States, Victor Koehl & Co.

The same amount of seed was sown on plot No. III as was sown on the other plots but was untreated.

The seed germinated fairly well, but the plants grew considerably better on some portions of the plots than on others.

At the close of the growing season the plants were in a fairly good condition. The difference in stand and growth due to the different treatments was not great, the best, however, being on the plot treated with soil from the New York Station.

The stand on plot No. II was no better than that on plot No. III. No. II plot, however, improved considerably more during the second year than did plot No. III.

During the second year there appeared to be considerable difference in the growth of the alfalfa, due to the previous treatment of the plots. Those on which legumes had been grown appeared considerably better than those which produced timothy and millet.

The plots were cut June 22, soon after the plants were coming into bloom. The following table gives the yield of green substance and dry matter per acre:

| | Wt. fresh substance per acre. | Wt. air-dry matter per acre. |
|---|---|---|
| Plot No. I, soil inoculated, | 5,893 lbs. | 2,222 lbs. |
| Plot No. II, "Nitragin" treated, | 4,770 lbs. | 1,798 lbs. |
| Plot No. III, not treated, | 3,397 lbs. | 1,281 lbs. |

The above shows a considerable difference in favor of the plot treated with soil from alfalfa ground, and also some effect of the "Nitragin" treatment.

In all plots, however, the yield is much smaller than should be obtained from alfalfa under favorable conditions.

The subsequent winter killing of the plants over a considerable portion of the plots prevented a continuation of the test.

In conclusion it may be said that the results obtained from these tests indicate that it is of doubtful expediency to attempt to grow alfalfa on the shallow limestone soils of Pennsylvania when other legumes are more certain.

# METHODS OF STEER-FEEDING.

## A CO-OPERATIVE EXPERIMENT BY THE PENNSYLVANIA STATE DEPARTMENT OF AGRICULTURE AND THE PENNSYLVANIA STATE COLLEGE AGRICULTURAL EXPERIMENT STATION.

BY G. C. WATSON AND M. S. MCDOWELL.

At the suggestion of the Secretary of Agriculture, and upon a general plan devised by him, the following experiment upon methods of handling fattening steers has been carried out by the Department of Agriculture and the Experiment Station in co-operation. It is recognized that one season's experiment with fifteen animals is far from sufficient to settle the questions involved, and this bulletin is to be regarded as a preliminary report only. It is hoped to continue the trials through succeeding years.

The close margin at which fattening steers are being fed by the farmers of Pennsylvania compels them to look carefully for little wastes that heretofore have gone unchecked, and to secure the most efficient means of caring for their fattening animals at the least possible expense. On account of this close competition, the efficiency of methods employed for converting the coarse fodders of the farm and the commercial stock foods into beef are to be considered more closely than ever before, in order that the most economical way may be selected, and the necessary expenditures of money and labor reduced to a minimum.

### PLAN OF EXPERIMENT.

In order to ascertain the efficiency and practicability of certain methods, a practical steer-feeding experiment was devised for the purpose of determining, if possible:

1. The effect of different methods of supplying drinking water.
2. The efficiency of different methods of confining fattening animals.

In order to make a satisfactory test under practical conditions, a space to accommodate three lots of steers of five each was set apart in the basement of the College barn for this trial. The basement of this barn is 65x100 feet, with the ceiling 11 feet high, and is largely used each year for steer-feeding. Lot I occupied a pen or large box-stall 20 feet long and 11.5 feet wide, which is exactly the same space that five stalls had previously occupied, including the alley at the rear of the stalls used for access, cleaning them out, etc. Lot II occupied five stalls adjoining this pen. Lot III occupied five other stalls similar to those occupied by Lot II. Lot I, or those in the box-stall, were fed from a common manger and supplied with drinking water kept before them all the time in an automatic watering basin, except when the water was withheld for a short time previous to weighing periods. Lot II was also supplied with automatic watering basins similar to Lot I. Lot III was watered by turning them out, for an hour or two once each day, in a large yard adjoining the basement, where they were permitted to drink in common from a large watering trough. The steers in Lots I and II were not removed from the pens or stalls except as it was desired to weigh them on alternate weeks.

## ANIMALS.

The steers used in this experiment were purchased at the stock-yards at Pittsburg, November 20, 1899. They were dehorned grade Shorthorn steers, raised in northeastern Ohio, and were carefully selected as to size, age and quality, so far as appearances would indicate. While individual characteristics, which proved some animals to be somewhat more desirable feeders than others, developed as the feeding progressed, yet all would have been called good feeding steers, either at the beginning or at the close of the experiment. These steers were sorted into lots soon after purchasing, and were confined in the pen and stalls until December 14, when the experiment proper was begun. It was thought best to defer beginning the experiment for a few weeks, in order that the animals might become accustomed to their new surroundings, and also to give an opportunity to discard any animal that might prove objectionable.

## RATIONS FED.

Each lot was fed grain, consisting of six parts of corn and cob meal and one part of wheat bran by measure, in such quantities as presumably would be readily consumed. An accurate account was kept of the amount of grain consumed by each lot, but the amount fed from day to day was left to the judgment of an experienced feeder. The grain for each lot was weighed out weekly and placed in a bin. At the end of the week that remaining in the bin was weighed and deducted from the amount previously weighed out. A similar account was also kept of the hay and corn stover consumed by each lot. The individuals of each lot were weighed on alternate weeks.

The following table gives the amount of food consumed weekly by each lot:

*Food Consumed.*

| Date. | Lot. I. | | | Lot II. | | | Lot III. | | |
|---|---|---|---|---|---|---|---|---|---|
| For Week Ending. | Hay. | Fodder. | Grain. | Hay. | Fodder. | Grain. | Hay. | Fodder. | Grain. |
| Dec. 21, 1899,.. | 298.0 | 89.0 | 439.0 | 283.0 | 107.5 | 430.0 | 275.0 | 87.0 | 430.0 |
| Dec. 28, 1899,.. | 255.5 | 96.5 | 459.0 | 235.0 | 103.0 | 456.0 | 245.5 | 67.0 | 456.0 |
| Jan. 4, 1900,.. | 262.5 | 100.0 | 496.0 | 256.5 | 109.5 | 490.5 | 240.5 | 66.0 | 490.5 |
| Jan. 11, 1900,.. | 260.0 | 117.0 | 491.0 | 259.0 | 124.5 | 490.0 | 237.5 | 52.5 | 490.0 |
| Jan. 18, 1900,.. | 262.5 | 136.0 | 506.0 | 262.5 | 117.5 | 497.0 | 262.5 | 78.5 | 497.0 |
| Jan. 25, 1900,.. | 262.5 | 121.0 | 535.5 | 262.5 | 106.0 | 533.0 | 262.5 | 60.0 | 533.0 |
| Feb. 1, 1900,.. | 262.5 | 136.5 | 557.5 | 262.5 | 112.0 | 557.5 | 262.5 | 74.5 | 557.5 |
| Feb. 8, 1900,.. | 262.5 | 124.5 | 595.5 | 262.5 | 81.0 | 593.5 | 262.5 | 70.0 | 593.5 |
| Feb. 15, 1900,.. | 297.5 | 118.0 | 617.0 | 287.5 | 87.0 | 617.0 | 293.5 | 51.0 | 617.0 |
| Feb. 22, 1900,.. | 288.5 | 111.0 | 608.0 | 291.0 | 102.0 | 601.5 | 293.5 | 65.5 | 601.5 |
| Mar. 1, 1900,.. | 297.5 | 104.0 | 590.0 | 297.5 | 108.0 | 585.0 | 293.5 | 61.0 | 585.0 |
| Mar. 8, 1900,.. | 297.5 | 112.0 | 619.5 | 297.5 | 98.5 | 619.5 | 295.0 | 63.0 | 619.5 |
| Mar. 15 1900,.. | 297.5 | 112.5 | 638.0 | 294.5 | 99.5 | 632.0 | 290.5 | 62.0 | 632.0 |
| Mar. 22, 1900,.. | 297.5 | 91.0 | 639.0 | 285.5 | 83.0 | 623.0 | 296.0 | 46.5 | 623.0 |
| Mar. 29, 1900,.. | 322.5 | .......... | 617.5 | 326.0 | .......... | 618.5 | 308.5 | .......... | 618.5 |
| Apr. 5, 1900,.. | 327.25 | .......... | 515.0 | 327.25 | .......... | 497.0 | 321.25 | .......... | 497.0 |
| Apr. 12, 1900,.. | 327.25 | .......... | 539.5 | 323.25 | .......... | 522.0 | 316.25 | .......... | 522.5 |
| Apr. 19, 1900,.. | 327.25 | .......... | 596.5 | 324.25 | .......... | 575.5 | 300.75 | .......... | 575.5 |
| Apr. 26, 1900,.. | 327.25 | .......... | 610.0 | 319.25 | .......... | 605.0 | 287.25 | .......... | 605.0 |
| Total, ..... | 5533.50 | 1568.00 | 10663.5 | 5457.00 | 1439.0 | 10543.5 | 5339.50 | 904.5 | 10544.00 |

The hay consumed by the three lots was of good and uniform quality, largely timothy, with a little clover. The corn stover was well cured and shredded. The grain, as explained before, consisted of corn and cob meal and wheat bran, six parts of the former to one part of the latter by measure, or 10 pounds of meal to 0.9 pounds of bran. The hay and corn stover were placed in large sacks and weighed on scales, and taken from the sacks and placed in the mangers as required. That remaining in the mangers was weighed and deducted from the total amount offered them, the difference giving the amount consumed. As the refuse in many cases was inconsiderable, it was not weighed back until a quantity had accumulated in the mangers. During the whole experiment, it was observed that Lot I was eating the hay somewhat closer than the other two lots, although this difference seemed to be so slight that it was not thought best to change the quantity offered them. The total amount of refuse, however, for the lot is shown by the following tabular statement:

*Amounts of hay and stover offered and amounts refused.*

| | Hay offered. | Hay refused. | Stover offered. | Stover refused. |
|---|---|---|---|---|
| Lot I, | 5533.0 | 54.5 | 2512.5 | 944.5 |
| Lot II, | 5457.0 | 131.0 | 2512.5 | 1073.5 |
| Lot III, | 5339.0 | 258.5 | 2510.5 | 1606.0 |

It will be observed that Lots I and II refused less hay and less stover than Lot III. In other words, the lots to which water was supplied continually consumed nearly the same amounts of coarse fodder. These two lots in this respect differed from each other much less than either differed from Lot III. Each lot was offered the same weight of hay and stover. It should be noticed, however, that the difference in the amount of coarse fodder refused varied much more in the case of the corn stover than in the case of hay. For some reason Lot III did not relish the corn stover so well as either of the other two lots. While this may be due somewhat to the individuality of the lot, yet the difference cannot be ascribed wholly to this without further trials. In determining the amount of stover consumed by each lot, the refuse was weighed back and carefully sampled, a moisture determination made, and the weight calculated to the original state of moisture. While it is true that the chemical composition of the refuse would have differed somewhat from the original substance, yet the amount of dry matter consumed was accurately determined.

## WEIGHTS AND GAINS.

In the case of nearly every animal the increase in weight throughout the experiment showed considerable variation, no doubt largely due to the amount of water retained in the system at the time of weighing. In each case the weighing was done at 9 A. M., and after water had been withheld for 18 hours. In but two instances was there shown to be an actual loss from the previous weight; steer No. 93 in Lot I and steer No. 81 in Lot III each, on the 5th of April, weighed less than at the previous weighing, March 22. This may be accounted for, in part at least, by the fact that after April 1, corn meal was supplied in place of corn and cob meal, the proportion of bran being the same as before. This change of feed seemed to affect the animals somewhat unfavorably for a day or so, but they soon came back to their former appetites and consumed their rations with the usual relish. Such fluctuations of weight, following changes of feed, are not uncommon, being apparently due chiefly to changes in the amount of offal contained in the digestive organs. They serve to warn us that changes of live-weight during short periods are a very ncertain test of the real effect of a ration.

## *Weight of Steers at Each Weighing.*

| Steer No. | Dec. 14. | Dec. 28. | Jan. 11. | Jan. 25. | Feb. 8. | Feb. 22. | Mar. 8. | Mar. 22 | Apr. 5. | Apr. 19. |
|---|---|---|---|---|---|---|---|---|---|---|
| Lot I: | | | | | | | | | | |
| 91, | 1072.0 | 1100.0 | 1160.0 | 1192.0 | 1210.0 | 1232.5 | 1330.0 | 1370.0 | 1402.5 | 1450.0 |
| 92, | 990.0 | 1020.0 | 1042.0 | 1092.0 | 1105.0 | 1132.5 | 1190.0 | 1230.0 | 1255.0 | 1290.0 |
| 93, | 895.0 | 950.0 | 961.0 | 975.0 | 985.0 | 990.0 | 1060.0 | 1117.5 | 1102.5 | 1150.0 |
| 94, | 998.0 | 1007.0 | 1043.5 | 1048.0 | 1065.0 | 1102.5 | 1167.5 | 1200.0 | 1210.0 | 1260.0 |
| 95, | 1065.0 | 1130.0 | 1152.5 | 1182.0 | 1195.0 | 1217.5 | 1290.0 | 1332.5 | 1355.5 | 1402.5 |
| Total, | 5020.0 | 5207.0 | 5359.0 | 5489.0 | 5560.0 | 5675.0 | 6037.5 | 6250.0 | 6325.5 | 6552.5 |
| Lot II: | | | | | | | | | | |
| 86, | 985.0 | 1037.5 | 1077.5 | 1097.5 | 1122.5 | 1182.5 | 1202.5 | 1235.0 | 1245.0 | 1292.5 |
| 87, | 892.5 | 927.5 | 977.5 | 1004.5 | 1030.0 | 1070.0 | 1112.5 | 1155.0 | 1155.0 | 1227.5 |
| 88, | 927.5 | 957.5 | 1007.0 | 1019.5 | 1050.0 | 1085.0 | 1112.5 | 1137.5 | 1152.5 | 1202.5 |
| 89, | 972.5 | 972.5 | 1010.0 | 1029.0 | 1062.5 | 1082.5 | 1105.0 | 1130.0 | 1147.5 | 1187.5 |
| 90, | 974.5 | 1027.5 | 1065.0 | 1100.0 | 1119.0 | 1180.0 | 1222.5 | 1250.0 | 1270.0 | 1310.0 |
| Total, | 4752.0 | 4922.5 | 5137.0 | 5250.5 | 5384.0 | 5600.0 | 5755.0 | 5907.5 | 5970.0 | 6220.0 |
| Lot III: | | | | | | | | | | |
| 81, | 952.5 | 998.5 | 1022.5 | 1060.0 | 1072.5 | 1110.0 | 1150.0 | 1187.5 | 1184.0 | 1252.5 |
| 82, | 1002.5 | 1045.0 | 1087.5 | 1125.5 | 1145.0 | 1200.0 | 1215.0 | 1255.0 | 1283.0 | 1317.5 |
| 83, | 997.5 | 1032.5 | 1055.5 | 1095.00 | 1125.0 | 1175.0 | 1198.5 | 1222.5 | 1255.0 | 1295.0 |
| 84, | 1072.5 | 1090.0 | 1123.0 | 1155.5 | 1180.0 | 1232.5 | 1250.0 | 1270.0 | 1300.0 | 1337.5 |
| 85, | 957.5 | 977.5 | 1012.5 | 1035.0 | 1071.0 | 1108.5 | 1142.5 | 1152.5 | 1180.0 | 1200.0 |
| Total, | 4982.5 | 5143.5 | 5301.0 | 5471.0 | 5593.5 | 5826.0 | 5956.0 | 6087.5 | 6202.0 | 6402.5 |

*Table showing the gain of each steer throughout the experiment in periods of two weeks each.*

| Steer No. | Dec. 14. | Dec. 28. | Jan. 11. 1900. | Jan. 25. | Feb. 8. | Feb. 22. | Mar. 8. | Mar. 22 | Apr. 5. | Apr. 19. |
|---|---|---|---|---|---|---|---|---|---|---|
| Lot I: | | | | | | | | | | |
| 91, | ............ | 28 | 60 | 32 | 18 | 22.5 | 97.5 | 40 | 33.5 | 47.5 |
| 92, | ............ | 30 | 22 | 50 | 13 | 27.5 | 57.5 | 40 | 25 | 35 |
| 93, | ............ | 55 | 11 | 14 | 10 | 5 | 70 | 57.5 | *—15 | 47.5 |
| 94, | ............ | 9 | 36.5 | 4.5 | 17 | 37.5 | 65 | 32.5 | 10 | 50 |
| 95, | ............ | 65 | 22.5 | 29.5 | 13 | 22.5 | 72.5 | 42.5 | 23 | 47 |
| Total, | ............ | 187 | 152 | 130 | 71 | 115 | 362.5 | 212.5 | 76.5 | 227 |
| Lot II: | | | | | | | | | | |
| 86, | ............ | 52.5 | 40 | 20 | 25 | 60 | 20 | 32.5 | 10 | 47.5 |
| 87, | ............ | 35 | 50 | 27 | 25.5 | 40 | 42.5 | 42.5 | 00 | 72.5 |
| 88, | ............ | 30 | 49.5 | 12.5 | 30.5 | 35 | 27.5 | 25 | 15 | 50 |
| 89, | ............ | 00 | 37.5 | 19 | 23.5 | 20 | 22.5 | 25 | 17.5 | 40 |
| 90, | ............ | 53 | 37.5 | 35 | 19 | 61 | 42.5 | 27.5 | 20 | 40 |
| Total, | ............ | 170.5 | 214.5 | 113.5 | 123.5 | 216 | 155 | 152.5 | 62.5 | 250 |
| Lot III: | | | | | | | | | | |
| 81, | ............ | 46 | 24 | 37.5 | 12.5 | 27.5 | 40 | 37.5 | *—3.5 | 68.5 |
| 82, | ............ | 42.5 | 42.5 | 38 | 19.5 | 55 | 15 | 40 | 28 | 34.5 |
| 83, | ............ | 35 | 23 | 29.5 | 30 | 50 | 23.5 | 24 | 33 | 40 |
| 84, | ............ | 17.5 | 33 | 32.5 | 24.5 | 52.5 | 17.5 | 20 | 30 | 37.5 |
| 85, | ............ | 20 | 35 | 22.5 | 36 | 37.5 | 34 | 10 | 27.5 | 20 |
| Total, | ............ | 161 | 157.5 | 170 | 122.5 | 222.5 | 130 | 131.5 | 114.5 | 200.5 |

*Weighed less than at the previous weighing.

*Gain of each individual of each lot.*

| | Steer No. | First weighing. | Last weighing. | Total gain, lbs. | Gain Per cent. | Gain per day, lbs. |
|---|---|---|---|---|---|---|
| Lot I, | 91 | 1072.0 | 1450.0 | 378.0 | 35.26 | 3.00 |
| | 92 | 990.0 | 1290.0 | 300.0 | 30.30 | 2.38 |
| | 93 | 895.0 | 1150.0 | 255.0 | 28.49 | 2.02 |
| | 94 | 998.0 | 1260.0 | 262.0 | 26.25 | 2.08 |
| | 95 | 1065.0 | 1402.5 | 337.5 | 31.69 | 2.68 |
| Total, | ............ | 5020.0 | 6552.5 | 1532.5 | 30.53 | 12.16 |
| Lot II, | 86 | 985.0 | 1292.5 | 307.5 | 31.22 | 2.44 |
| | 87 | 892.5 | 1227.5 | 335.0 | 37.53 | 2.66 |
| | 88 | 927.5 | 1202.5 | 275.0 | 29.65 | 2.18 |
| | 89 | 972.5 | 1187.5 | 215.0 | 22.11 | 1.71 |
| | 90 | 974.5 | 1310.0 | 335.5 | 34.43 | 2.66 |
| Total, | ............ | 4752.0 | 6220.0 | 1468.0 | 30.89 | 11.65 |
| Lot III, | 81 | 952.5 | 1252.5 | 300.0 | 31.49 | 2.38 |
| | 82 | 1002.5 | 1317.5 | 315.0 | 31.42 | 2.50 |
| | 83 | 997.5 | 1295.0 | 297.5 | 29.77 | 2.36 |
| | 84 | 1072.5 | 1337.5 | 265.0 | 24.71 | 2.10 |
| | 85 | 957.5 | 1200.0 | 242.5 | 25.33 | 1.92 |
| Total, | ............ | 4982.5 | 6402.5 | 1420.0 | 28.50 | 11.26 |

From the above table it will be readily seen that Lot No I made the greatest gain per day, although the gain in percentage over the original weight did not quite equal that of Lot No. II. In Lot No. I, every animal gained more than two pounds per day, and one equalled or exceeded three pounds. In each of the other two lots there was at least one animal whose daily average gain was below two pounds per day during the whole time of the experiment.

The following table gives the amount of food consumed by each lot per pound of gain in live weight:

*Food Consumed per Pound Gained in Live Weight.*

| | Hay. | Stover. | Grain. |
|---|---|---|---|
| Lot I, | 3.61 | 1.02 | 6.95 |
| Lot II, | 3.72 | .96 | 7.18 |
| Lot III, | 3.76 | .64 | 7.43 |

There was not very much difference in the amount of hay consumed by the three lots per pound of gain in live weight, but the corn stover and grain varied considerably more. Lot III refused to eat as much corn stover as either Lot I or Lot II, but consumed about 7 per cent. more grain for the same gain in live weight than Lot I.

It has been given as a reason for not feeding several steers in a pen that there was more danger of being a great variation in the gain than where stall feeding is practiced; in other words, that there would be more underlings that would not receive their proportion of food and would not therefore make so good gains as if they were protected from their larger and stronger companions. While a bunch of five steers is not sufficiently large to show whether this would be a serious objection, yet from the data secured from this trial the indications are that there is practically no difference in regard to this point. At any rate, the gain of the individual animals in Lot No. I is quite as uniform as in Lots II and III.

### LABOR REQUIRED.

The following tabular statement indicates the amount of time in hours required for one man to care for each lot during the entire time of the trial:

*Time of one man required for attendance.*

| | Hours. | Percentage of Lot III. |
|---|---|---|
| Lot I, | 93.66 | 76.0 |
| Lot II, | 113.33 | 92.0 |
| Lot III, | 123.25 | ............... |

It will be noticed that Lot No. I received much less attention than either Lots II or III. In other words, it was found that one man could attend to more animals in pens than would be possible where each individual was kept in a stall. It required much less time to clean out the stables, and it also took less time to properly litter or distribute the bedding. The stables were cleaned daily for Lots II and III, but from Lot I the manure was taken out only a few times during the whole experiment. In each case the same amount of litter was given each lot. Early in the experiment it was found that the anmials in Lot I were keeping very much cleaner than the animals of Lots II and III. As all the animals were kept clean by the use of the brush and currycomb, a considerably less time was necessary for this purpose in the case of Lot II than either of the other two lots.

### CONCLUSIONS.

So far as any conclusions are warranted from a single experiment with a few animals, the above results would seem to indicate that dehorned steers can be fed in pens, in the manner practiced with Lot I, with at least as satisfactory results as regards gain as when handled in the more common way, while there is a very considerable saving in the amount of work required to properly care for them.

The self-watering device also saved considerable work and possibly effected some economy in the amount of grain consumed per pound of gain, although the unavoidable differences between the lots render this conclusion far from certain.

# OBSERVATIONS ON SEPARATORS.

By Harry Hayward.

During the Creamery Course of 1900, three different makes of power separators were used and records were kept of the performance of each. While this work was not done with the degree of accuracy which would be expected in exhaustive tests of separators, the results nevertheless give a fair idea of what may be expected under the varying conditions of creamery practice and of the completeness with which cream may be separated when proper care is used.

Three machines were used, namely the United States No. 1, manufactured by the Vermont Farm Machine Company, Bellows Falls, Vermont, having a rated capacity of 2300 to 2500 lbs. of milk per hour at 8,000 revolutions per minute; the Sharpless Tubular, manufactured by P. M. Sharples, West Chester, Pa., having a rated capacity of 2500 lbs. of milk per hour at 24,000 revolutions per minute; and the Alpha Acme, manufactured by the DeLaval Separator Co., New York City, having a rated capacity of 1500 to 1750 lbs. of milk per hour at 6,000 revolutions per minute. The fat was determined by the Babcock method, the double-necked bottle being used for the skim milk.

## *United States.*

| Date. | Temperature of milk. Fahr. | Feed per hour. Lbs. | Velocity of bowl. Revolutions per minute. | Per cent. fat in milk. | Per cent. fat in skim milk. | Per cent. fat in cream. |
|---|---|---|---|---|---|---|
| January 5, | 85 | 2,745 | 7,000 | 4.6 | .025 | 22.5 |
| January 6, | 85 | 2,412 | 7,000 | 4.0 | .2 | 25.0 |
| January 8, | 85 | 3,000 | 7,200 | 4.3 | .22 | 14.5 |
| January 9, | 85 | 2,100 | 7,000 | 4.6 | .05 | 22.0 |
| January 10, | 85 | 2,045 | 7,000 | 4.45 | .02 | 20.05 |
| January 11, | 85 | 2,200 | 7,700 | 4.6 | .12 | 22.0 |
| January 12, | 85 | 2,456 | 7,000 | 4.3 | .25 | 20.0 |
| January 13, | 85 | 2,700 | 7,300 | 4.6 | .08 | 25.2 |
| January 15, | 80 | 2,340 | 7,000 | 4.4 | .11 | 20.0 |
| January 16, | 86 | 3,120 | 7,000 | 4.6 | .12 | 19. |
| January 17, | 85 | 2,250 | 7,400 | 4.5 | .07 | 22.5 |
| January 18, | 85 | 2,530 | 7,400 | 4.6 | .04 | 26.00 |
| January 19, | 78 | 2,445 | 8,000 | 4.6 | .035 | 20.00 |
| January 20, | 82 | 2,587 | 8,200 | 4.6 | .045 | 24.00 |
| January 22, | 85 | 2,500 | 8,000 | 4.2 | .05 | 25.00 |
| January 23, | 82 | 2,580 | 8,000 | 4.3 | .025 | 45.00 |
| January 24, | 100 | 2,310 | 7,950 | 4.2 | .035 | 50.00 |

## *Sharpless Tubular.*

| Date. | Temperature of milk. Fahr. | Feed per hour. Lbs. | Velocity of bowl. Revolutions per minute. | Per cent. fat in milk. | Per cent. fat in skim milk. | Per cent. fat in cream. |
|---|---|---|---|---|---|---|
| January 25, | 95 | 2,035 | 24,000 | 4.3 | .10 | 20.5 |
| January 26, | 95 | 2,520 | 23,000 | 4.4 | .12 | 36.0 |
| January 27, | 84 | 2,610 | 24,000 | 4.5 | .05 | 36.00 |
| January 29, | 85 | 2,610 | 24,000 | 4.4 | .05 | 46.00 |
| January 30, | 85 | 2,940 | 23,200 | 4.6 | .02 | 34.00 |
| January 31, | 85 | 2,310 | 23,200 | 4.4 | .05 | 47.00 |
| February 1, | 84 | 2,400 | 23,000 | 4.4 | .14 | 47.00 |
| February 2, | 82 | 2,640 | 23,300 | 4.6 | .08 | 29.5 |
| February 3, | 85 | 2,610 | 24,000 | 4.7 | .02 | 35.5 |
| February 5, | 85 | 3,000 | 24,000 | 4.4 | .015 | 27.00 |
| February 6, | 87 | 2,700 | 23,000 | 4.4 | .07 | 32.00 |
| February 7, | 85 | 3,080 | 23,500 | 4.6 | .08 | 35.00 |
| February 8, | 95 | 2,700 | 22,100 | 4.4 | .08 | 30.5 |
| February 9, | 86 | 2,580 | 24,000 | 4.4 | .08 | 32.00 |
| February 10, | 90 | 2,898 | 24,000 | 4.5 | .10 | 31.40 |
| February 11, | 85 | 2,700 | 24,000 | 4.0 | .08 | 36.00 |

## *Acme DeLaval.*

| Date. | Temperature of milk. Fahr. | Feed per hour. Lbs. | Velocity of bowl. Revolutions per minute. | Per cent. fat in milk. | Per cent. fat in skim milk. | Per cent. fat in cream. |
|---|---|---|---|---|---|---|
| January 5, | 85 | 1,440 | 6,000 | 4.6 | .01 | 35.00 |
| January 6, | 85 | 1,635 | 6,400 | 4.3 | .03 | 40.00 |
| January 9, | 85 | 1,350 | 6,000 | 4.6 | .02 | 45.00 |
| January 10, | 85 | 1,200 | 5,800 | 4.5 | .05 | 34.00 |
| January 11, | 85 | 1,515 | 6,000 | 4.6 | .02 | 35.2 |
| January 12, | 85 | 1,740 | 6,200 | 4.6 | .025 | 26.00 |
| January 13, | 85 | 1,560 | 5,600 | 4.2 | .03 | 24.00 |
| January 15, | 80-85 | 1,620 | 6,000 | 4.4 | .05 | 23.5 |
| January 16, | 80 | 1,800 | 6,000 | 4.2 | .12 | 25.00 |
| January 17, | 85 | 1,500 | 6,000 | 4.4 | .03 | 24.00 |
| January 18, | 85 | 1,440 | 6,000 | 4.2 | .02 | 23.5 |
| January 19, | 84 | 1,800 | 6,000 | 4.8 | .02 | 27.00 |
| January 20, | 85 | 1,387 | 6,350 | 4.2 | .01 | 27.5 |
| January 22, | 82 | 1,770 | 5,800 | 4.4 | .04 | 19.5 |
| January 23, | 87 | 1,572 | 5,200 | 4.3 | .075 | 21.5 |
| January 24, | 85 | 1,696 | 6,000 | 4.0 | .03 | 26.5 |
| January 25, | 85 | 1,650 | 6,000 | 4.5 | .05 | 25. |
| January 26, | 85 | 1,620 | 6,000 | 4.1 | .05 | 23.00 |
| January 27, | 85 | 1,620 | 6,000 | 4.5 | .03 | 27.00 |
| January 29, | 85 | 1,665 | 5,900 | 4.3 | .02 | 24.0 |
| January 30, | 85 | .......... | 6,000 | 4.2 | .03 | 24.00 |
| January 31, | 85 | 1,560 | 6,000 | 4.8 | .01 | 23. |
| February 1, | 85 | 1,320 | 6,000 | 4.6 | .025 | 28.5 |
| February 2, | 86 | 1,680 | 6,000 | 4.1 | .02 | 24. |
| February 3, | 85 | 1,475 | 6,000 | 4.5 | .02 | 32.5 |
| February 5, | 85 | 1,560 | 5,550 | 4.1 | .01 | 22. |
| February 6, | 85 | 1,590 | 5,800 | 3.9 | .03 | 22.00 |
| February 7, | 85 | 1,680 | 6,000 | 4.4 | .02 | 25.5 |
| February 8, | 85 | 1,680 | 6,200 | 4.2 | .02 | 23.0 |
| February 9, | 85 | 1,560 | 6,000 | 5.7 | .......... | .......... |
| February 10, | 86 | 1,560 | 6,000 | 4.0 | .03 | 24. |

In considering the above results, it should be noted that in several cases, as appears from the tables, the machines were run either above their rated capacity or below their rated speed. This was especially the case with the United States machine, with which the rated speed was reached only in the last five runs. This was due in some instances to a deficiency of power and in others was purposely done in order to demonstrate to students the effect of varying these conditions.

Taking the records as a whole, they plainly show the high degree of perfection which has been reached in the manufacture of separators, and that with a reasonable degree of care and skill in operation the loss of fat in the skim milk may be reduced to an exceedingly small quantity.

# THE MANURIAL VALUE OF THE EXCRETA OF MILCH COWS.

By W. S. Sweetser.*

This experiment formed a part of a much more extensive one the object of which was to determine the effect of food upon the amount and character of dairy products. The object of this part was to determine what proportion of each fertilizing element finds its way into each of the materials excreted by a cow in full milk. Milk is here considered as one of the excretions.

There were two cows connected with this branch of the experiment, which was divided into five periods of 40 days each. During the last 10 days of each period, the cows were put upon digestion trials. The ration of the cow Cena was planned to be the same throughout the entire experiment and to consist of

| | |
|---|---|
| 15 lbs. | mixed hay, |
| 3 lbs. | cottonseed meal, |
| 2 lbs. | linseed meal, |
| 2 lbs. | corn meal, |
| 1 lb. | buckwheat middlings, |

with a nutritive ratio of 1:3.9 based upon average composition rather than upon actual chemical analysis.

Laurie's rations, as planned for each period, ran as follows:

| | Period I. Lbs. | Period II. Lbs. | Period III. Lbs. | Period IV. Lbs. | Period V. Lbs. |
|---|---|---|---|---|---|
| Mixed hay, | 15 | 15 | 15 | 15 | 15 |
| Cottonseed meal, | 3 | 1 | ¼ | 1 | 3 |
| Linseed meal, | 2 | 1 | ¼ | 1 | 2 |
| Corn meal, | 2 | 5 | 7 | 5 | 2 |
| Buckwheat middlings, | 1 | 1 | ⅓ | 1 | 1 |
| Nutritive ratio, | 1:3.9 | 1:6.1 | 1:8.7 | 1:6.1 | 1:3.9 |

The amounts of hay actually eaten varied somewhat from the above figures. Table I includes the weight of hay and grain eaten, the nutritive ratio of each cow's ration and the weights of feces, urine and milk for each digestion period. The mixed hay consisted of about equal parts of clover and timothy.

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*This investigation was made by Mr. Sweetser while Assistant Chemist of the Station.

*Table I.---Food and Excreta.*

| | Mixed hay. Lbs. | Mixed grain. Lbs. | Nutritive ratio. | Fresh feces. Lbs. | Urine. Lbs. | Milk. Lbs. |
|---|---|---|---|---|---|---|
| **Period I:** | | | | | | |
| Cena, | 150 | 80 | 1:3.9 | 406.5 | 304.3 | 233.5 |
| Laurie, | 150 | 80 | 1:3.9 | 398.5 | 305.0 | 274.0 |
| **Period II:** | | | | | | |
| Cena, | 160 | 80 | 1:3.9 | 467.9 | 273.7 | 236.8 |
| Laurie, | 180 | 80 | 1:6.3 | 417.2 | 246.7 | 223.5 |
| **Period III:** | | | | | | |
| Cena, | 167.5 | 80 | 1:4.0 | 462.7 | 223.0 | 215.3 |
| Laurie, | 187.5 | 80 | 1:8.7 | 498.2 | 273.5 | 216.8 |
| **Period IV:** | | | | | | |
| Cena, | 170 | 80 | 1:4.0 | 494.0 | 251.2 | 204.3 |
| Laurie, | 190 | 80 | 1:6.3 | 481.6 | 223.1 | 214.8 |
| **Period V:** | | | | | | |
| Cena, | 180 | 80 | 1:4.1 | 495.2 | 252.8 | 192.4 |
| Laurie, | 170 | 80 | 1:4.0 | 445.6 | 228.3 | 208.0 |

Table II contains the percentages of nitrogen, phosphoric acid and potash in the hay, grain, feces, urine and milk. The phosphoric acid and potash in the food and feces were determined in the air-dried materials and calculated to the fresh substances. The nitrogen was determined in the air-dried foods, but with the excreta it was determined in the fresh substance. In the case of the feces the samples for analysis were taken from well-mixed composite samples preserved with carbon bi-sulphid.

The milk samples of period I were destroyed before the work on this part of the experiment was undertaken. In computing the weights of nitrogen, phosphoric acid and potash for this period, the weights of milk were multiplied by the means of the percentages for the other four periods.

## *Table II.---Percentages of Fertilizing Ingredients in Food and Excreta.*

| Sample No. | Material. | Loss in air-drying. | In Air-dried Substance. | | | In Fresh Substance. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Nitrogen. | Phosphoric acid. | Potash. | Nitrogen. | Phosphoric acid. | Potash. |
| | **Period I.** | | | | | | | |
| 21394 | Hay, | 7.25 | 2.02 | 0.549 | 2.19 | 1.870 | .509 | 2.03 |
| 21475 | Hay, | 10.40 | 2.30 | 0.661 | 2.78 | 2.060 | .592 | 2.49 |
| 21534 | Grain, | 5.50 | 5.41 | 1.840 | 1.25 | 5.110 | 1.740 | 1.18 |
| 21709 | Feces, Cena, | 81.21 | ............... | 2.290 | 0.89 | 0.500 | 0.430 | 0.17 |
| 21710 | Feces, Laurie, | 81.52 | ............... | 2.200 | 0.87 | 0.515 | 0.407 | 0.16 |
| 21711 | Urine, Cena, | ............... | ............... | ............... | ............... | 1.505 | 0.030 | 1.36 |
| 21712 | Urine, Laurie, | ............... | ............... | ............... | ............... | 1.250 | 0.007 | 1.04 |
| | **Period II.** | | | | | | | |
| 21920 | Hay, | 8.20 | 2.19 | 0.578 | 2.25 | 2.010 | 0.531 | 2.06 |
| 22051 | Grain, | 4.60 | 5.40 | 1.940 | 1.23 | 5.150 | 1.855 | 1.17 |
| 22052 | Grain, | 7.83 | 3.48 | 1.385 | 0.83 | 3.160 | 1.276 | 0.76 |
| 22126 | Feces, Cena, | 81.60 | ............... | 1.835 | 0.86 | 0.485 | 0.338 | 0.16 |
| 22127 | Feces, Laurie, | 81.40 | ............... | 1.640 | 1.00 | 0.467 | 0.305 | 0.19 |
| 22128 | Urine, Cena, | ............... | ............... | ............... | ............... | 1.455 | 0.005 | 1.06 |
| 22129 | Urine, Laurie, | ............... | ............... | ............... | ............... | 1.060 | 0.005 | 1.05 |
| 22067 | Milk, Cena, | ............... | ............... | ............... | ............... | 0.480 | 0.217 | 0.20 |
| 22069 | Milk, Laurie, | ............... | ............... | ............... | ............... | 0.495 | 0.190 | 0.20 |
| | **Period III.** | | | | | | | |
| 22777 | Hay, | 8.55 | 2.34 | 0.585 | 2.08 | 2.140 | 0.540 | 1.90 |
| 22934 | Hay, | 8.27 | 2.36 | 0.580 | 2.25 | 2.160 | 0.530 | 2.06 |
| 23039 | Grain, | 6.00 | 5.36 | 2.030 | 1.25 | 5.040 | 1.910 | 1.18 |
| 23040 | Grain, | 9.83 | 2.09 | 0.870 | 0.64 | 1.880 | 0.780 | 0.58 |
| 23189 | Feces, Cena, | 80.29 | ............... | 1.945 | 0.68 | 0.496 | 0.380 | 0.13 |
| 23190 | Feces, Laurie, | 81.86 | ............... | 1.205 | 0.71 | 0.461 | 0.220 | 0.13 |
| 23191 | Urine, Cena, | ............... | ............... | ............... | ............... | 1.400 | 0.050 | 1.06 |
| 23192 | Urine, Laurie, | ............... | ............... | ............... | ............... | 0.840 | 0.030 | 1.07 |
| 23098 | Milk, Cena, | ............... | ............... | ............... | ............... | 0.480 | 0.210 | 0.19 |
| 23099 | Milk, Laurie, | ............... | ............... | ............... | ............... | 0.500 | 0.200 | 0.19 |

*Table II--Continued.*

| Sample No. | Material. | Loss in air-drying. | In Air-dried Substance. | | | In Fresh Substance. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Nitrogen. | Phosphoric Acid. | Potash. | Nitrogen. | Phosphoric Acid. | Potash. |
| | **Period IV.** | | | | | | | |
| 23963 | Hay, | 6.87 | 2.13 | 0.485 | 2.11 | 1.980 | 0.450 | 1.97 |
| 24094 | Hay, | 5.20 | 2.23 | 0.510 | 2.22 | 2.110 | 0.480 | 2.10 |
| 24234 | Grain, | 6.67 | 5.01 | 2.340 | 1.40 | 4.680 | 2.180 | 1.31 |
| 24235 | Grain, | 8.83 | 3.18 | 1.420 | 0.90 | 2.900 | 1.290 | 0.82 |
| 24300 | Feces, Cena, | 81.71 | ... | 2.150 | 0.75 | 0.476 | 0.390 | 0.14 |
| 24301 | Feces, Laurie, | 82.71 | ... | 1.515 | 0.81 | 0.439 | 0.260 | 0.14 |
| 24302 | Urine, Cena, | ... | ... | ... | ... | 1.480 | 0.040 | 1.29 |
| 24303 | Urine, Laurie, | ... | ... | ... | ... | 1.070 | 0.050 | 1.18 |
| 24264 | Milk, Cena, | ... | ... | ... | ... | 0.510 | 0.230 | 0.21 |
| 24265 | Milk, Laurie, | ... | ... | ... | ... | 0.520 | 0.200 | 0.20 |
| | **Period V.** | | | | | | | |
| 25030 | Hay, | 3.47 | 1.55 | 0.360 | 2.10 | 1.500 | 0.350 | 2.08 |
| 25210 | Hay, | 7.47 | 1.82 | 0.500 | 2.62 | 1.680 | 0.460 | 2.42 |
| 25318 | Grain, | 5.00 | 4.91 | 2.230 | 1.33 | 4.660 | 2.120 | 1.26 |
| 25354 | Feces, Cena, | 82.10 | ... | 1.790 | 0.98 | 0.410 | 0.320 | 0.18 |
| 25355 | Feces, Laurie, | 81.90 | ... | 2.010 | 0.99 | 0.420 | 0.360 | 0.18 |
| 25356 | Urine, Cena, | ... | ... | ... | ... | 1.560 | 0.005 | 1.76 |
| 25357 | Urine, Laurie, | ... | ... | ... | ... | 1.510 | 0.005 | 1.63 |
| 25344 | Milk, Cena, | ... | ... | ... | ... | 0.540 | 0.233 | 0.20 |
| 25345 | Milk, Laurie, | ... | ... | ... | ... | 0.510 | 0.197 | 0.20 |

Tables III, IV and V show the amounts of nitrogen, phosphoric acid and potash respectively which were eaten by each cow in the hay and grain and excreted in the feces, urine and milk. They also show what proportions of each of these three fertilizing elements passed into the feces, urine and milk respectively.

The last column but one in each of these tables shows the relation between the amounts of nitrogen, phosphoric acid or potash digested and the amounts excreted. The last column in each of these three tables gives the ratio between the amount contained in the urine and that contained in the milk.

## *Table.---Nitrogen.*

| Eaten by Cena. | | | Excreted by Cena. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period I. | | | | | | | |
| 21394 | Hay, | 1.496 | 21709 | Feces, | 2.033 | 25.51 | | |
| 21475 | Hay, | 1.648 | 21711 | Urine, | 4.580 | 57.49 | 88.08 | 1: |
| 21534 | Grain, | 4,068 | | Milk, | 1.355 | 17.00 | 26.05 | 0.2957 |
| | Total, | 7.212 | | Total, | 7.968 | 100.00 | 114.13 | |
| | Period II. | | | | | | | |
| 21920 | Hay, | 3.216 | 22126 | Feces, | 2.269 | 30.70 | | |
| 22051 | Grain, | 4.120 | 22128 | Urine, | 3.983 | 53.92 | 78.59 | 1: |
| | | | 22067 | Milk, | 1.136 | 15.38 | 22.42 | 0.2852 |
| | Total, | 7.336 | | Total, | 7.388 | 100.00 | 101.00 | |
| | Period III. | | | | | | | |
| 22777 | Hay, | 1.766 | 23189 | Feces, | 2.296 | 29.30 | | |
| 22934 | Hay, | 1.836 | 23191 | Urine, | 4.508 | 57.53 | 84.47 | 1: |
| 23039 | Grain, | 4.032 | 23098 | Milk, | 1.033 | 13.17 | 19.85 | 0.2351 |
| | Total, | 7.634 | | Total, | 7.837 | 100.00 | 104.32 | |
| | Period IV. | | | | | | | |
| 23963 | Hay, | 1.683 | 24300 | Feces, | 2.352 | 33.08 | | |
| 24094 | Hay, | 1.793 | 24302 | Urine, | 3.717 | 52.27 | 76.37 | 1: |
| 24234 | Grain, | 3.744 | 24264 | Milk, | 1.042 | 14.65 | 21.40 | 0.2802 |
| | Total, | 7.220 | | Total, | 7.111 | 100.00 | 97.77 | |

| | Period V. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 25080 | Hay, | 1.320 | 25354 | Feces, | 2.010 | 28.74 | ............ | ............ |
| 25210 | Hay, | 1.512 | 25356 | Urine, | 3.944 | 56.40 | 86.10 | 1: |
| 25318 | Grain, | 3.728 | 25344 | Milk, | 1.039 | 14.86 | 22.68 | 0.2634 |
| | Total, | 6.560 | | Total, | 6.993 | 100.00 | 108.78 | ............ |

## *Table III---Nitrogen---Continued.*

| Eaten by Laurie. | | | Excreted by Laurie. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period I. | | | | | | | |
| 21394 | Hay, | 1.683 | 21710 | Feces, | 2.053 | 25.53 | ............... | ............... |
| 21475 | Hay, | 1.854 | 21712 | Urine, | 4.591 | 57.09 | 82.37 | 1: |
| 21534 | Grain, | 4.088 | | Milk, | 1.397 | 17.38 | 25.07 | 0.3043 |
| | Total, | 7.625 | | Total, | 8.041 | 100.00 | 107.44 | ............... |
| | Period II. | | | | | | | |
| 21920 | Hay, | 3.618 | 22127 | Feces, | 1.948 | 34.15 | ............... | ............... |
| 22052 | Grain, | 2.528 | 22129 | Urine, | 2.615 | 45.83 | 62.29 | 1: |
| | | | 22068 | Milk, | 1.142 | 20.02 | 27.20 | 0.4367 |
| | Total, | 6.146 | | Total, | 5.705 | 100.00 | 89.49 | ............... |
| | Period III. | | | | | | | |
| 22777 | Hay, | 1.980 | 23190 | Feces, | 2.297 | 40.47 | ............... | ............... |
| 22934 | Hay, | 2.052 | 23192 | Urine, | 2.297 | 40.47 | 70.92 | 1: |
| 23040 | Grain, | 1.504 | 23099 | Milk, | 1.083 | 19.06 | 33.44 | 0.4715 |
| | Total, | 5.536 | | Total, | 5.677 | 100.00 | 104.36 | ............... |
| | Period IV. | | | | | | | |
| 23963 | Hay, | 1.881 | 24301 | Feces, | 2.114 | 37.64 | ............... | ............... |
| 24094 | Hay, | 2.005 | 24302 | Urine, | 2.386 | 42.50 | 58.32 | 1: |
| 24235 | Grain, | 2.320 | 24265 | Milk, | 1.116 | 19.86 | 27.27 | 0.4677 |
| | Total, | 6.206 | | Total, | 5.616 | 100.00 | 85.59 | ............... |

Period V.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 25030 | Hay, | 1.275 | 25355 | Feces, | 2.092 | 31.72 | ................ | ................ |
| 25210 | Hay, | 1.428 | 25357 | Urine, | 3.447 | 52.33 | 72.41 | 1: |
| 25318 | Grain, | 3.728 | 25345 | Milk, | 1.051 | 15.95 | 24.21 | 0.3049 |
| | Total, | 6.431 | | Total, | 6.588 | 100.00 | 103.68 | ................ |

### *Table III.---Summary. Nitrogen--- Weights and Percentage Distribution---Cena.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, ............... | 2.033 | 25.51 | 2.269 | 30.70 | 2.296 | 29.30 | 2.352 | 33.08 | 2.010 | 28.74 |
| Urine, ............... | 4.580 | 57.49 | 3.983 | 53.92 | 4.508 | 57.53 | 3.717 | 52.27 | 3.944 | 56.40 |
| Milk, ............... | 1.355 | 17.00 | 1.136 | 15.38 | 1.033 | 13.17 | 1.042 | 14.65 | 1.039 | 14.86 |
| Total, ......... | 7.968 | 100.00 | 7.388 | 100.00 | 7.837 | 100.00 | 7.111 | 100.00 | 6.993 | 100.00 |

### *Nitrogen---Laurie.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, ............... | 2.053 | 25.53 | 1.948 | 34.15 | 2.297 | 40.47 | 2.114 | 37.64 | 2.090 | 31.72 |
| Urine, ............... | 4.591 | 57.09 | 2.615 | 45.83 | 2.297 | 40.47 | 2.386 | 42.50 | 3.447 | 52.32 |
| Milk, ............... | 1.397 | 17.38 | 1.142 | 20.02 | 1.083 | 19.06 | 1.116 | 19.86 | 1.051 | 15.96 |
| Total, ......... | 8.041 | 100.00 | 5.705 | 100.00 | 5.677 | 100.00 | 5.616 | 100.00 | 6.588 | 100.00 |

## *Nitrogen---Percentage Distribution.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, .............. | 4.086 | 25.52 | 4.217 | 32.43 | 4.593 | 34.89 | 4.466 | 35.36 | 4.100 | 30.23 |
| Urine, .............. | 9.171 | 57.29 | 6.598 | 49.87 | 6.805 | 49.00 | 6.103 | 47.39 | 7.391 | 54.37 |
| Milk, ............... | 2.752 | 17.19 | 2.278 | 17.70 | 2.116 | 16.11 | 2.158 | 17.25 | 2.090 | 15.40 |
| Total, ......... | 16.009 | 100.00 | 13.093 | 100.00 | 13.514 | 100.00 | 12.727 | 100.00 | 13.581 | 100.00 |

It will be noticed in Table III, that with the cow Cena whose ration was nearly constant, the proportions of nitrogen in the excretions were comparatively constant. In the feces the proportions of the total nitrogen excreted ranged from 25.51 per cent. to 33.08 per cent.; in the urine from 52.27 per cent. to 57.53 per cent., and in the milk from 13.17 per cent. to 17.00 per cent. With Laurie there was a decided change in the percentage distribution which followed the change in the nutritive ratio of her ration. The following figures from Table III show the changes which occurred in the percentage distribution of the nitrogen during the five periods:

*Nitrogen---Cena and Laurie,*

| | Period I. | Period II. | Period III. | Period IV. | Period V. |
|---|---|---|---|---|---|
| **Cena:** | | | | | |
| Nutritive ratio, | 1:3.9 | 1:3.9 | 1:3.9 | 1:3.9 | 1:3.9 |
| Feces, | 25.51 | 30.70 | 29.30 | 33.08 | 28.74 |
| Urine, | 57.49 | 53.92 | 57.53 | 52.27 | 56.40 |
| Milk, | 17.00 | 15.38 | 13.17 | 14.65 | 14.86 |
| **Laurie:** | | | | | |
| Nutritive ratio, | 1:3.9 | 1:6.3 | 1:8.7 | 1:6.3 | 1:4.0 |
| Feces, | 25.53 | 34.15 | 40.47 | 37.64 | 31.72 |
| Urine, | 57.09 | 45.83 | 40.47 | 42.50 | 52.33 |
| Milk, | 17.38 | 20.02 | 19.06 | 19.86 | 15.95 |

The proportion of nitrogen in Laurie's milk was fairly constant, but seems to show a slight tendency to increase as the nutritive ratio widened. She drew a little more heavily upon the nitrogen of her food to supply the demands of her milk secretion. As her nutritive ratio widened the proportion of nitrogen excreted in the feces increased, and a corresponding decrease is shown in the urine. The reverse holds true as the nutritive ratio narrows again. This change in the digestibility of the protein is explained by the fact that a greater proportion of the protein was contained in the hay, with the wide ratios, and such protein is less digestible than that in the grain fed.

Of the nitrogen which passed into the circulation, quite a constant percentage passed into the milk in the case of Cena. With Laurie this percentage increased as the nutritive ratio widened. The following figures show what percentage of the resorbed nitrogen found its way into the milk in each period:

*Resorbed Nitrogen---Percentage Found in Milk.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. |
|---|---|---|---|---|---|
| Cena: | | | | | |
| Nutritive ratio, ........... | 1:3.9 | 1:3.9 | 1:3.9 | 1:3.9 | 1:3.9 |
| Percentage, ................ | 22.8 | 22.2 | 22.9 | 21.9 | 20.9 |
| Laurie: | | | | | |
| Nutritive ratio, ........... | 1:3.9 | 1:6.3 | 1:8.7 | 1:6.3 | 1:4.0 |
| Percentage, ................ | 23.3 | 30.4 | 32.0 | 31.9 | 23.4 |

This may be explained in part by taking into consideration the amounts of nitrogen fed and digested during each period by each cow.

*Nitrogen Fed and Digested.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. |
|---|---|---|---|---|---|
| Cena: | | | | | |
| Nitrogen fed, lbs.,...... | 7.232 | 7.336 | 7.634 | 7.220 | 6.590 |
| Nitrogen digested, lbs.,. | 5.935 | 5.119 | 5.541 | 4.759 | 4.983 |
| Nitrogen digested, per cent., .................. | 74.49 | 69.30 | 70.70 | 66.92 | 71.26 |
| Laurie: | | | | | |
| Nitrogen fed, lbs., ...... | 7.625 | 6.146 | 5.536 | 6.206 | 6.431 |
| Nitrogen digested, lbs.,. | 5.988 | 3.757 | 3.380 | 3.502 | 4.498 |
| Nitrogen digested, per cent., .................. | 74.47 | 65.85 | 59.53 | 62.36 | 68.28 |

With Laurie the amounts of nitrogen fed and digested decreased very materially as the nutritive ratio widened and increased again as the ratio became narrower. Possibly during the middle periods the animal digested an amount insufficient to supply the demands both of renewing tissue and secreting her usual quantity of milk, and the latter demand was met at the expense of the former. Had the cow digested more protein the results might have been quite different.

## *Table IV.---Phosphoric Acid, $P_2O_5$.*

| Eaten by Cena. | | | Excreted by Cena. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period I. | | | | | | | |
| 21394 | Hay, | 0.407 | 21709 | Feces, | 1.748 | 72.53 | ............... | ............... |
| 21475 | Hay, | 0.474 | 21711 | Urine, | 0.091 | 3.78 | 17.33 | 1: |
| 21534 | Grain, | 1.392 | | Milk, | 0.571 | 23.69 | 108.70 | 6.275 |
| | Total, | 2.273 | | Total, | 2.410 | 100.00 | 126.03 | ............... |
| | Period II. | | | | | | | |
| 21920 | Hay, | 0.850 | 22126 | Feces, | 1.581 | 74.96 | ............... | ............... |
| 22051 | Grain, | 1.484 | 22123 | Urine, | 0.014 | 0.66 | 1.86 | 1: |
| | | | 22067 | Milk, | 0.514 | 24.38 | 68.26 | 36.70 |
| | Total, | 2.334 | | | | | | |
| | Period III. | | | Total, | 2.109 | 100.00 | 70.12 | ............... |
| 22777 | Hay, | 0.445 | 23189 | Feces, | 1.758 | 78.95 | ............... | ............... |
| 22934 | Hay, | 0.451 | 23191 | Urine, | 0.017 | 0.76 | 2.55 | 1: |
| 23039 | Grain, | 1.528 | 23098 | Milk, | 0.452 | 20.29 | 67.85 | 26.61 |
| | Total, | 2.424 | | Total, | 2.227 | 100.00 | 70.40 | ............... |
| | Period IV. | | | | | | | |
| 23963 | Hay, | 0.383 | 24300 | Feces, | 1.927 | 79.93 | ............... | ............... |
| 24094 | Hay, | 0.408 | 24302 | Urine, | 0.012 | 0.50 | 1.97 | 1: |
| 24234 | Grain, | 1.746 | 24264 | Milk, | 0.472 | 19.57 | 77.38 | 39.27 |
| | Total, | 2.537 | | Total, | 2.411 | 100.00 | 79.35 | ............... |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Period V. | | | | | | | |
| 25030 | Hay, | 0.315 | 24354 | Feces, | 1.585 | 77.47 | ............ | ............ |
| 25210 | Hay, | 0.414 | 25356 | Urine, | 0.013 | 0.63 | 1.55 | 1: |
| 25318 | Grain, | 1.696 | 25344 | Milk, | 0.448 | 21.90 | 53.33 | 34.41 |
| | Total, | 2.425 | | Total, | 2.046 | 100.00 | 54.88 | ............ |

## *Table IV---Phosphoric Acid.---Continued.*

| Eaten by Laurie. | | | Excreted by Laurie. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period I. | | | | | | | |
| 21394 | Hay, ........ | 0.458 | 21710 | Feces, ........ | 1.622 | 74.07 | .............. | .............. |
| 21475 | Hay, ........ | 0.533 | 21712 | Urine, ........ | 0.020 | 0.91 | 2.63 | 1: |
| 21534 | Grain, ........ | 1.392 | | Milk, ........ | 0.548 | 25.02 | 72.01 | 27.38 |
| | Total, ........ | 2.383 | | Total, ........ | 2.190 | 100.00 | 74.64 | .............. |
| | Period II. | | | | | | | |
| 21920 | Hay, ........ | 0.956 | 22127 | Feces, ........ | 1.272 | 74.04 | .............. | .............. |
| 22052 | Grain, ........ | 1.021 | 22129 | Urine, ........ | 0.012 | 0.70 | 1.70 | 1: |
| | | | 22068 | Milk, ........ | 0.434 | 25.26 | 61.56 | 36.21 |
| | Total, ........ | 1.977 | | Total, ........ | 1.718 | 100.00 | 63.26 | .............. |
| | Period III. | | | | | | | |
| 22777 | Hay, ........ | 0.500 | 23190 | Feces, ........ | 1.096 | 67.78 | .............. | .............. |
| 22934 | Hay, ........ | 0.503 | 23192 | Urine, ........ | 0.088 | 5.44 | 16.58 | 1: |
| 23040 | Grain, ........ | 0.624 | 23099 | Milk, ........ | 0.433 | 26.78 | 81.55 | 4.92 |
| | Total, ........ | 1.627 | | Total, ........ | 1.617 | 100.00 | 98.13 | .............. |
| | Period IV. | | | | | | | |
| 23963 | Hay, ........ | 0.428 | 24301 | Feces, ........ | 1.252 | 74.17 | .............. | .............. |
| 24094 | Hay, ........ | 0.456 | 24303 | Urine, ........ | 0.011 | 0.65 | 1.66 | 1: |
| 24235 | Grain, ........ | 1.032 | 24265 | Milk, ........ | 0.425 | 25.18 | 64.00 | 38.56 |
| | Total, ........ | 1.916 | | Total, ........ | 1.688 | 100.00 | 65.66 | .............. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Period V. | | | | | | | |
| 25030 | Hay, | 0.298 | 25355 | Feces, | 1.604 | 79.25 | ............ | ............ |
| 25210 | Hay, | 0.391 | 25357 | Urine, | 0.010 | 0.49 | 1.28 | 1: |
| 25318 | Grain, | 1.696 | 25,345 | Milk, | 0.410 | 20.26 | 52.49 | 41.01 |
| | Total, | 2.385 | | Total, | 2.024 | 100.00 | 53.77 | ............ |

## *Table IV.---Summary.*

### *Phosphoric Acid, $P_2O_5$.---Weights and Percentage Distribution---Cena.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, .............. | 1.748 | 72.53 | 1.581 | 74.96 | 1.758 | 78.95 | 1.927 | 79.93 | 1.585 | 77.47 |
| Urine, .............. | 0.091 | 3.78 | 0.014 | 0.66 | 0.017 | 0.76 | 0.012 | 0.50 | 0.013 | 0.63 |
| Milk, ................ | 0.571 | 23.69 | 0.514 | 24.38 | 0.452 | 20.29 | 0.472 | 19.57 | 0.448 | 21.90 |
| Total, ......... | 2.410 | 100.00 | 2.109 | 100.00 | 2.227 | 100.00 | 2.411 | 100.00 | 2.046 | 100.00 |

### *Phosphoric Acid---Laurie.*

| | Period I. | | Period II. | | Period III. | | Period IV | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, .............. | 1.622 | 74.07 | 1.272 | 74.04 | 1.096 | 67.78 | 1.252 | 74.17 | 1.604 | 79.25 |
| Urine, .............. | 0.020 | 0.91 | 0.012 | 0.70 | 0.088 | 5.44 | 0.011 | 0.65 | 0.010 | 0.49 |
| Milk, ................ | 0.548 | 25.02 | 0.434 | 25.26 | 0.433 | 26.78 | 0.425 | 25.18 | 0.410 | 20.26 |
| Total, ......... | 2.190 | 100.00 | 1.718 | 100.00 | 1.617 | 100.00 | 1.688 | 100.00 | 2.024 | 100.00 |

## *Phosphoric Acid---Cena and Laurie.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, .............. | 3.370 | 73.30 | 2.853 | 74.50 | 2.854 | 73.37 | 3.179 | 77.05 | 3.189 | 78.36 |
| Urine, .............. | 0.111 | 2.34 | 0.026 | 0.68 | 0.105 | 3.10 | 0.023 | 0.58 | 0.023 | 0.56 |
| Milk, ............... | 1.119 | 24.36 | 0.948 | 24.82 | 0.885 | 23.53 | 0.897 | 22.37 | 0.858 | 21.08 |
| Total, ......... | 4.600 | 100.00 | 3.827 | 100.00 | 3.844 | 100.00 | 4.099 | 100.00 | 4.070 | 100.00 |

The amount of phosphoric acid which passed into the urine was almost insignificant all through the experiment, so that practically all which passed into the blood circulation passed into the milk or was retained in the body, and this held true throughout the five periods although the milk flow fell off about one-fourth. It would be interesting to know what would have been the case had the experiment continued to the close of the lactation periods. The following figures, if we except Period V of Laurie, show that here was a tendency for both cows to digest a higher percentage of the phosphoric acid as the amount in the food diminished:

*Phosphoric Acid Fed and Digested.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. |
|---|---|---|---|---|---|
| **Cena:** | | | | | |
| Phosphoric acid in food, pounds, | 2.273 | 2.334 | 2.424 | 2.537 | 2.425 |
| Phosphoric acid digested, per cent., | 27.47 | 25.04 | 21.05 | 20.07 | 22.53 |
| **Laurie:** | | | | | |
| Phosphoric acid in food, pounds, | 2.383 | 1.977 | 1.627 | 1.916 | 2.385 |
| Phosphoric acid digested, per cent., | 25.93 | 25.96 | 32.22 | 25.83 | 20.75 |

## *Table V.—Potash, $K_2O$.*

| Eaten by Cena. | | | Excreted by Cena. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period I. | | | | | | | |
| 21394 | Hay, | 1.624 | 21709 | Feces, | 0.679 | 12.59 | ........ | ........ |
| 21475 | Hay, | 1.992 | 21711 | Urine, | 4.138 | 76.71 | 106.60 | 1: |
| 21534 | Grain, | 0.944 | | Milk, | 0.577 | 10.70 | 14.87 | 0.1395 |
| | Total, | 4.560 | | Total, | 5.394 | 100.00 | 121.47 | ........ |
| | Period II. | | | | | | | |
| 21920 | Hay, | 3.298 | 22126 | Feces, | 0.739 | 14.38 | ........ | ........ |
| 22061 | Grain, | 0.936 | 22128 | Urine, | 3.924 | 76.39 | 112.30 | 1: |
| | | | 22067 | Milk, | 0.474 | 9.23 | 13.56 | 0.1208 |
| | Total, | 4.234 | | Total, | 5.137 | 100.00 | 125.86 | ........ |
| | Period III. | | | | | | | |
| 22777 | Hay, | 1.567 | 23183 | Feces, | 0.601 | 13.59 | ........ | ........ |
| 22934 | Hay, | 1.751 | 23191 | Urine, | 3.413 | 77.18 | 93.24 | 1: |
| 23039 | Grain, | 0.944 | 23096 | Milk, | 0.409 | 9.23 | 11.17 | 0.1198 |
| | Total, | 4.262 | | Total, | 4.423 | 100.00 | 104.41 | ........ |
| | Period IV. | | | | | | | |
| 23963 | Hay, | 1.674 | 24300 | Feces, | 0.692 | 15.86 | ........ | ........ |
| 24094 | Hay, | 1.785 | 24302 | Urine, | 3.241 | 74.30 | 84.92 | 1: |
| 24234 | Grain, | 1.049 | 24264 | Milk, | 0.429 | 9.84 | 11.24 | 0.1323 |
| | Total, | 4.508 | | Total, | 4.362 | 100.00 | 96.16 | ........ |

## *Table V.---Potash---Continued.*

| Eaten by Cena. | | | Excreted by Cena. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period V. | | | | | | | |
| 25030 | Hay, ........................ | 1.827 | 25354 | Feces, ............ | 0.891 | 15.56 | ............... | ............... |
| 25210 | Hay, ........................ | 2.178 | 25356 | Urine, ............ | 4.449 | 77.71 | 108.00 | 1: |
| 25318 | Grain, ........................ | 1.008 | 25344 | Milk, ............ | 0.385 | 6.73 | 9.34 | 0.0865 |
| | Total, ........................ | 5.012 | | Total, ........ | 5.725 | 100.00 | 117.34 | ............... |

## Table V.---Potash---Continued.

| Eaten by Laurie. | | | Excreted by Laurie. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period I. | | | | | | | |
| 21394 | Hay, | 1.827 | 21710 | Feces, | 0.642 | 14.77 | .............. | .............. |
| 21475 | Hay, | 2.241 | 21712 | Urine, | 3.157 | 76.62 | 72.24 | 1: |
| 21534 | Grain, | 0.944 | | Milk, | 0.548 | 12.61 | 12.54 | 0.1736 |
| | Total, | 5.012 | | Total, | 4.347 | 100.00 | 84.78 | .............. |
| | Period II. | | | | | | | |
| 21920 | Hay, | 3.708 | 22127 | Feces, | 0.772 | 20.21 | .............. | .............. |
| 22052 | Grain, | 0.608 | 22129 | Urine, | 2.590 | 67.82 | 73.08 | 1: |
| | | | 22068 | Milk, | 0.457 | 11.97 | 12.89 | 0.1764 |
| | Total, | 4.316 | | Total, | 3.819 | 100.00 | 86.97 | .............. |
| | Period III. | | | | | | | |
| 22777 | Hay, | 1.757 | 23190 | Feces, | 0.648 | 16.30 | .............. | .............. |
| 22934 | Hay, | 1.957 | 23192 | Urine, | 2.926 | 73.61 | 82.88 | 1: |
| 23040 | Grain, | 0.464 | 23099 | Milk, | 0.401 | 10.09 | 11.36 | 0.1371 |
| | Total, | 4.178 | | Total, | 3.975 | 100.00 | 94.24 | .............. |
| | Period IV. | | | | | | | |
| 23963 | Hay, | 1.871 | 24301 | Feces, | 0.674 | 18.04 | .............. | .............. |
| 24094 | Hay, | 1.995 | 24303 | Urine, | 2.633 | 70.45 | 68.44 | 1: |
| 24235 | Grain, | 0.656 | 24265 | Milk, | 0.430 | 11.51 | 11.18 | 0.1632 |
| | Total, | 4.522 | | Total, | 3.737 | 100.00 | 79.62 | .............. |

## *Table V.---Potash---Continued.*

| Eaten by Laurie. | | | Ecreted by Laurie. | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Substance. | Pounds. | Sample No. | Substance. | Pounds. | Per cent. of total excretion. | Pounds per 100 lbs. digested. | Ratio. |
| | Period V. | | | | | | | |
| 25030 | Hay, | 1.726 | 25355 | Feces, | 0.802 | 16.24 | ............... | ............... |
| 25210 | Hay, | 2.057 | 25357 | Urine, | 3.721 | 75.34 | 93.26 | 1: |
| 25318 | Grain, | 1.008 | 25345 | Milk, | 0.416 | 8.42 | 10.42 | 0.1117 |
| | Total, | 4.791 | | Total, | 4.939 | 100.00 | 103.68 | ............... |

### *Table V.---Summary.*

### *Potash, $K_2O$.--- Weights and Percentage Distribution---Cena.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, | 0.679 | 12.59 | 0.739 | 14.38 | 0.601 | 13.59 | 0.692 | 15.86 | 0.891 | 15.56 |
| Urine, | 4.138 | 76.71 | 3.924 | 76.39 | 3.413 | 77.18 | 3.241 | 74.30 | 4.449 | 77.71 |
| Milk, | 0.577 | 10.70 | 0.474 | 9.23 | 0.409 | 9.23 | 0.429 | 9.84 | 0.385 | 6.73 |
| Total, | 5.394 | 100.00 | 5.137 | 100.00 | 4.423 | 100.00 | 4.362 | 100.00 | 5.725 | 100.00 |

### *Potash---Laurie.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, | 0.642 | 14.77 | 0.772 | 20.21 | 0.648 | 16.30 | 0.674 | 18.04 | 0.802 | 16.24 |
| Urine, | 3.157 | 72.62 | 2.590 | 67.82 | 2.926 | 73.61 | 2.633 | 70.45 | 3.721 | 75.34 |
| Milk, | 0.548 | 12.61 | 0.457 | 11.97 | 0.401 | 10.09 | 0.430 | 11.51 | 0.416 | 8.42 |
| Total, | 4.347 | 100.00 | 3.819 | 100.00 | 3.975 | 100.00 | 3.737 | 100.00 | 4.939 | 100.00 |

*Potash--Cena and Laurie.*

| | Period I. | | Period II. | | Period III. | | Period IV. | | Period V. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, .............. | 1.321 | 13.68 | 1.511 | 17.25 | 1.249 | 14.95 | 1.366 | 16.94 | 1.693 | 15.90 |
| Urine, .............. | 7.295 | 74.67 | 6.514 | 72.10 | 6.339 | 75.39 | 5.874 | 72.39 | 8.170 | 76.53 |
| Milk, ............... | 1.125 | 11.65 | 0.931 | 10.65 | .810 | 9.66 | 0.859 | 10.67 | 0.801 | 7.57 |
| Total, ......... | 9.741 | 100.00 | 8.956 | 100.00 | 8.398 | 100.00 | 8.099 | 100.00 | 10.664 | 100.00 |

In table V no relation is traced between the amount of potash fed and that digested. The one thing very noticeable is the large amount which passed from the food into the circulation and thence into the urine. These amounts ranged from 67.82 per cent. of the total amount excreted in Laurie's period II, to 77.71 per cent. in Cena's period V.

Table VI presents the combined weights of the nitrogen, phosphoric acid and potash respectively of the five periods for each cow, together with their percentage distribution. Roughly speaking, the feces contained one-third of the nitrogen and three-fourths of the phosphoric acid excreted, while the urine contained one-half of the nitrogen and three-fourths of the potash.

### *Table VI.---Nitrogen, Phosphoric Acid and Potash.*

*Five Periods, 50 Days.---Weights and Percentage Distribution---Cena.*

| | Nitrogen. | | Phosphoric Acid. | | Potash. | |
|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, ............................ | 10.96 | 29.40 | 8.60 | 76.71 | 3.60 | 14.38 |
| Urine, ............................ | 20.73 | 55.58 | 0.15 | 1.34 | 19.16 | 76.51 |
| Milk, ............................ | 5.60 | 15.02 | 2.46 | 21.95 | 2.28 | 9.11 |
| Total, ...................... | 37.29 | 100.00 | 11.21 | 100.00 | 25.04 | 100.00 |

*Five Periods, 50 Days---Laurie.*

| | Nitrogen. | | Phosphoric Acid. | | Potash. | |
|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, ............................ | 10.50 | 33.20 | 6.85 | 74.13 | 3.54 | 17.00 |
| Urine, ............................ | 15.34 | 48.49 | 0.14 | 1.52 | 15.03 | 72.19 |
| Milk, ............................ | 31.63 | 100.00 | 9.24 | 100.00 | 20.82 | 100.00 |
| Total, ...................... | 31.63 | 100.00 | 9.24 | 100.00 | 20.82 | 100.00 |

## *Five Periods, 50 Days---Cena and Laurie.*

| | Nitrogen. | | Phosphoric Acid. | | Potash. | |
|---|---|---|---|---|---|---|
| | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. | Pounds. | Per cent. of total excretion. |
| Feces, | 21.46 | 31.14 | 15.45 | 75.55 | 7.14 | 15.58 |
| Urine, | 36.07 | 52.33 | 0.29 | 1.42 | 34.19 | 74.56 |
| Milk, | 11.39 | 16.53 | 4.71 | 23.03 | 4.53 | 9.86 |
| Total, | 68.92 | 100.00 | 20.45 | 100.00 | 45.86 | 100.00 |

## *Table VII.---Value of Nitrogen in Different Excretions.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. | Total. |
|---|---|---|---|---|---|---|
| **Cena:** | | | | | | |
| Feces, | $0.244 | $0.273 | $0.276 | $0.282 | $0.241 | $1.32 |
| Urine, | .550 | .478 | .541 | .446 | .478 | 2.49 |
| Milk, | .163 | .136 | .124 | .125 | .125 | 0.67 |
| Total, | .956 | .887 | .941 | .853 | .839 | 4.48 |
| **Laurie:** | | | | | | |
| Feces, | .246 | .234 | .276 | .254 | .251 | 1.26 |
| Urine, | .551 | .314 | .276 | .286 | .414 | 1.84 |
| Milk, | .168 | .137 | .130 | .134 | .126 | .70 |
| Total, | .965 | .685 | .682 | .674 | .791 | 3.80 |
| **Cena and Laurie:** | | | | | | |
| Feces, | .490 | .507 | .552 | .536 | .492 | 2.58 |
| Urine, | 1.101 | .792 | .817 | .732 | .887 | 4.83 |
| Milk, | .331 | .273 | .254 | .259 | .251 | 1.37 |
| Total, | 1.922 | 1.572 | 1.623 | 1.527 | 1.630 | 8.28 |

## *Table VIII.---Value of Phosphoric Acid in Different Excretions.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. | Total. |
|---|---|---|---|---|---|---|
| **Cena:** | | | | | | |
| **Feces,** | $0.070 | $0.063 | $0.070 | $0.077 | $0.063 | $0.343 |
| **Urine,** | .004 | .001 | .001 | .000 | .001 | .007 |
| **Milk,** | .023 | .021 | .018 | .019 | .018 | .099 |
| **Total,** | .097 | .085 | .089 | .096 | .082 | .449 |
| **Laurie:** | | | | | | |
| **Feces,** | .065 | .051 | .044 | .050 | .064 | .274 |
| **Urine,** | .001 | .000 | .004 | .000 | .000 | .005 |
| **Milk,** | .022 | .017 | .017 | .017 | .016 | .089 |
| **Total,** | .088 | .068 | .065 | .067 | .080 | .368 |
| **Cena and Laurie:** | | | | | | |
| **Feces,** | .135 | .114 | .114 | .127 | .127 | .617 |
| **Urine,** | .005 | .001 | .005 | .001 | .001 | .012 |
| **Milk,** | .045 | .038 | .035 | .036 | .034 | .188 |
| **Total,** | .185 | .153 | .154 | .164 | .162 | .817 |

## *Table IX.---Value of Potash in different Excretions.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. | Total. |
|---|---|---|---|---|---|---|
| **Cena:** | | | | | | |
| **Feces,** | $0.034 | $0.037 | $0.030 | $0.035 | $0.045 | $0.181 |
| **Urine,** | .207 | .196 | .171 | .162 | .222 | .958 |
| **Milk,** | .029 | .024 | .020 | .021 | .019 | .113 |
| **Total,** | .270 | .257 | .221 | .218 | .286 | 1.252 |
| **Laurie:** | | | | | | |
| **Feces,** | .032 | .039 | .032 | .034 | .040 | .177 |
| **Urine,** | .158 | .130 | .146 | .132 | .186 | .752 |
| **Milk,** | .027 | .023 | .020 | .022 | .021 | .113 |
| **Total,** | 217 | .192 | .198 | .188 | .247 | 1.042 |
| **Cena and Laurie:** | | | | | | |
| **Feces,** | .066 | .076 | .062 | .069 | .085 | .358 |
| **Urine,** | .365 | .326 | .317 | .294 | .408 | 1.710 |
| **Milk,** | .056 | .047 | .040 | .043 | .040 | .226 |
| **Total,** | .487 | .449 | .419 | .406 | .583 | 2.294 |

*Table X.—Total Manural Value of Different Excretions.*

| | Period I. | Period II. | Period III. | Period IV. | Period V. | Total. | Per cent. of total value. |
|---|---|---|---|---|---|---|---|
| **Cena:** | | | | | | | |
| Feces, ............ | $0.348 | $0.373 | $0.376 | $0.394 | $0.349 | $1.840 | 29.83 |
| Urine, ............ | .761 | .675 | .713 | .608 | .696 | 3.453 | 55.85 |
| Milk, ............ | .215 | .181 | .162 | .165 | .162 | .885 | 14.32 |
| Total, ....... | 1.324 | 1.229 | 1.251 | 1.167 | 1.207 | 6.178 | 100.00 |
| **Laurie:** | | | | | | | |
| Feces, ............ | .343 | .324 | .352 | .338 | .355 | 1.712 | 32.88 |
| Urine, ............ | .710 | .444 | .426 | .418 | .600 | 2.598 | 49.89 |
| Milk, ............ | .217 | .177 | .167 | .173 | .163 | .897 | 17.23 |
| Total, ...... | 1.270 | .945 | .945 | .929 | 1.118 | 5.207 | 100.00 |
| **Cena and Laurie:** | | | | | | | |
| Feces, ............ | .691 | .697 | .728 | .732 | .704 | 3.552 | 31.20 |
| Urine, ............ | 1.471 | 1.119 | 1.139 | 1.026 | 1.296 | 6.051 | 53.15 |
| Milk, ............ | .432 | .358 | .329 | .338 | .325 | 1.782 | 15.65 |
| Total, ...... | 2.594 | 2.174 | 2.196 | 2.096 | 2.325 | 11.385 | 100.00 |

Tables VII, VIII, IX and X give the values of the fertilizing ingredients, estimating nitrogen at 12 cents, phosphoric acid at 4 cents, and potash at 5 cents per pound. It is almost surprising to note how large a percentage of the manurial value, as given in the last column of table X, passed into the urine. It is not probable that these results are at all exceptional when it is noted that both cows all through the five periods (and in the ration of one cow a radical change was made for each period), gave practically the same result for each period. The urine contained almost none of the phosphoric acid but more than one-half of the nitrogen and three-fourths of the potash, the two most expensive of the manurial elements. If this is universally the case, how important is it that it should be considered by stockmen. Throwing the milk out of consideration, the urine contained 63 per cent. of the manurial value of the excretions. If it is allowed to run to waste as it too often does in large quantities, and as it must in many cases unless some effort is made toward its retention, a very great proportion of the plant food is lost. Undoubtedly the disregard for the value of the liquid manure has been a large factor in the "running down" of our older farms of the east. A great many of these farms are hungry for potash when in former years they possessed it in abundance. Potash is not easily washed from the soil. Where, then, has it gone? The high potash content of the urine of cattle, together with an utter disregard of its value is one answer to the above question.

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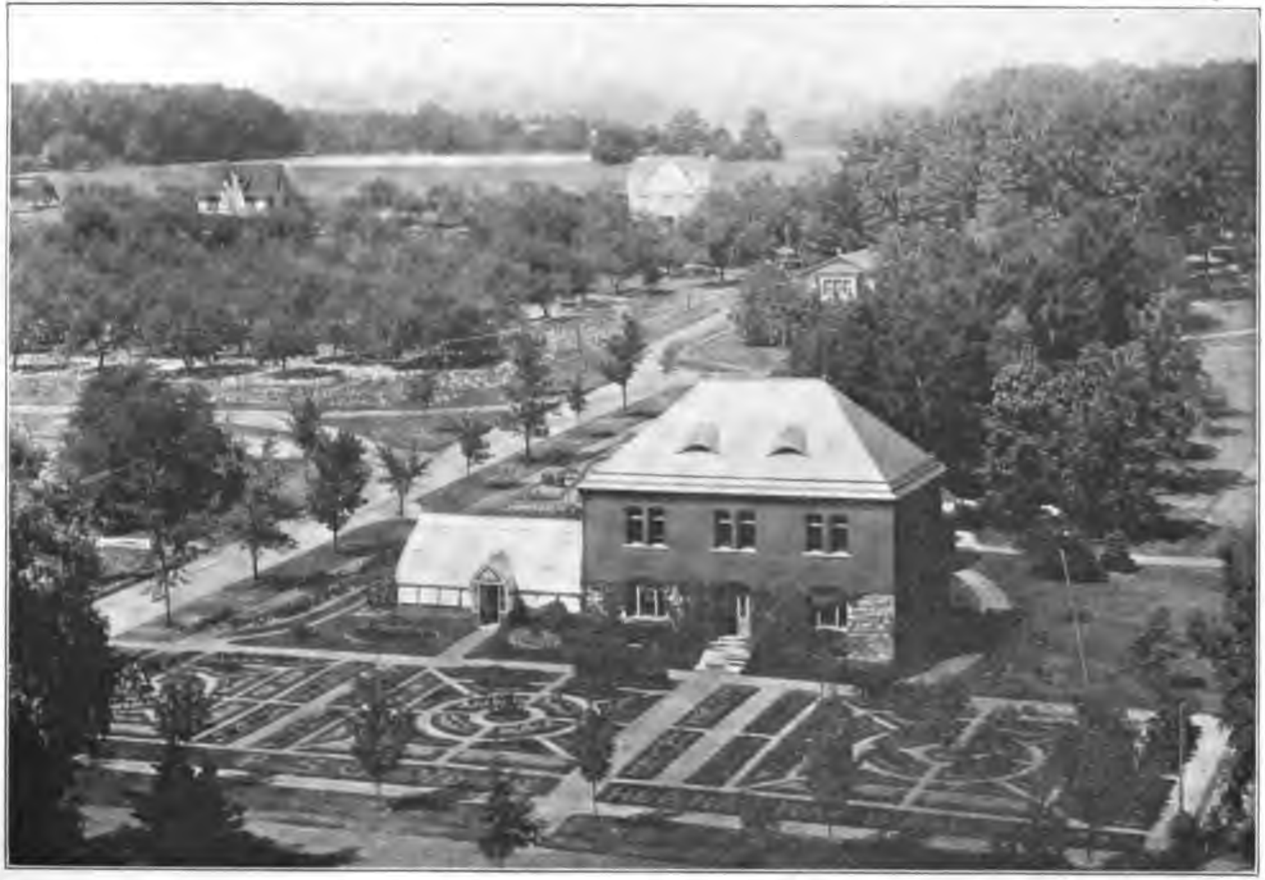


Botanical and Horticultural Building.

Whenever we see a brown liquor coming from the barnyard and running along the roadside, and too often making the thoroughfare itself a slough of filth, it should mean to us so many dollars and cents running to waste in the form of nitrogen and potash.

On the other hand this experiment illustrates the economy of stock-raising for various lines of production. Probably there is no branch of animal industry so exhaustive to the land as the production and sale of milk. Yet from the figures already produced only about 17 per cent. of the nitrogen, 23 per cent. of the phosphoric acid and 10 per cent. of the potash, or 15.65 per cent. of the manurial value of the feed was contained in the milk. The balance of the plant food under proper management would find its way back to the fields. If butter were made and the skim milk fed to hogs and calves, practically all of the fertilizing elements would be returned to the land.

# SMALL FRUITS IN 1900.

By J. P. Pillsbury.

## STRAWBERRIES.

This is the most popular, and deservedly so, of all small fruits. It is not so easy of cultivation, but is more profitable than any other. Given a fairly rich soil and plenty of water, and with shallow but thorough cultivation, one can grow it to perfection. But with strawberries as with any other crop, strict attention to business is the only way to success.

In planting it is best to select but three or four varieties, which, having successfully stood the tests of several years, are known to be of merit, and whose seasons of fruiting range from early to late. The Station has been investigating the merit of new varieties by testing them for a number of years. In all there were seventy-six varieties under cultivation here this year, but as a new bed was planted this spring and it required all of the plants of some of the later varieties received to fill up the space allotted to them, it is impossible to make any report upon all of them at present. A number of varieties which have been reported upon were left out of the new bed on account of successive poor yields, small berries and other reasons. They are as follows:

Bubach.
Champion.
Charles Downing.
Cumberland.
Darling.
Hay's Prolific.
Hull's No. 3.
H. W. Beecher.
Wilson's Albany.
Luther.
Maida No. 11860.
Monarch.
Mt. Vernon.

Several of the above varieties have been grown here for at least eight years, and for the last two or three have been getting weaker and weaker, producing smaller crops of much smaller berries than they ought, in spite of all that could be done with them. They seem to have "run out." It is expected that they will be replaced by new stock in the future, as they were useful as standards by which to judge newer varieties.

As good yields were expected for this season, it was very disappointing to find the totals, which will be found in the following tables, so low. Severe frosts and freezing weather which occurred soon after the flowering season opened, and which injured the tree fruits to a greater or less extent, and also the fact that the fruiting season of some varieties extended into the dry weather which occurred during the early part of July, stand as the probable explanation.

## DESCRIPTION OF THE TRIAL.

Each variety was cultivated both in hills and matted rows. The rows are three and one-half feet apart in the Station plot, and a row thirty feet in length occupies 105 square feet of ground or one-four hundred and fifteenth of an acre. As a rule, from one to two hundred bushels per acre is considered a good crop. One quart of berries, on an average, weighs 500 grams, so that a yield of 4,000 grams would be equivalent to 8 quarts. By multiplying this number by 415 the yield for an acre is estimated at 3,320 quarts or about 100 bushels. Thus a yield of 6,000 grams would mean at the rate of 150 bushels, and one of 8,000 grams, 200 bushels per acre. Of course some berries are quite solid, some are very light, and others are of such a shape that they can not be packed closely enough to weigh quite so much, but the weight of a quart ranges from 475 grams to 525 grams while a few run even as high as 550 grams.

In the following tables there are 38 varieties which have been grown for four years and whose average yield for that length of time is over 4,000 grams: One for three years; two for two years, and two for one year. The largest yield for a single season, recorded in the last four years, excepting 1898, (during which year this crop was a failure), was that of Mary in 1897, which was 12,595 grams. This means something over 300 bushels per acre or 25 quarts to every 30 feet of row.

*Varieties, Kind of Flower, Date of First Flower, First and Last Ripe Fruit, Yield, Rust, Runners and Vigor; scale 1 to 10---1 indicating very little, few or weak.*

| Name. | No. | P. Pistillate B. Bisexual | First flower. | First ripe. | Last ripe. | Scale of yield. 1 to 10. A. | Scale of yield. 1 to 10. B. | Rust. 1 to 10. | Runners. 1 to 10. | Vigor. 1 to 10. |
|---|---|---|---|---|---|---|---|---|---|---|
| Adam's Favorite, | 51 | P | May 8, | June 9, | June 25, | 3 | 2 | 3-4 | 9 | 8 |
| Banquet, | 14 | B | May 1, | June 4, | July 5, | 2 | 3 | 7-8 | 3 | 5 |
| Beebe, | 16 | B | May 2, | June 8, | July 5, | 3 | 3 | 5-6 | 2 | 4 |
| Boynton, | 26 | P | May 8, | June 6, | July 2, | 5 | 6 | 3-4 | 2 | 4 |
| Brandywine, | 23 | B | May 14, | June 11, | July 9, | 6 | 9 | 2-3 | 5 | 7 |
| Bryant, | 56 | B | May 12, | June 10, | July 2, | ...... | 3 | 3-4 | 8 | 6 |
| Bubach No. 5, | 13 | P | May 1, | June 3, | June 27, | 8 | 6 | 7-8 | 4 | 8 |
| Carrie, | 52 | P | April 30, | June 8, | June 27, | 2 | 2 | 3-4 | 9 | 8 |
| Champion, | 49 | P | May 8, | June 8, | July 2, | 2 | 3 | 8-9 | 8 | 7 |
| Chas. Downing, | 2 | B | May 2, | June 5, | July 5, | 3 | 4 | 7-8 | 3 | 8 |
| Crawford, | 30 | B | May 8, | June 4, | July 9, | 7 | 8 | 2-3 | 7 | 10 |
| Crescent, | 3 | P | May 2, | June 5, | July 2, | 6 | 4 | 8-9 | 9 | 8 |
| Cumberland, | 8 | B | May 10, | June 7, | July 5, | 3 | 3 | 5-6 | 3 | 7 |
| Darling, | 55 | B | May 2, | June 4, | June 27, | ...... | 3 | 5-6 | 2 | 6 |
| Dayton, | 41 | B | May 12, | June 8, | July 5, | 5 | 6 | 3-4 | 10 | 8 |
| Ella, | 53 | B | April 30, | June 4, | June 27, | 3 | 3 | 3-4 | 6 | 7 |
| Enhance, | 34 | B | May 1, | June 7, | July 2, | 4 | 5 | 3-4 | 3 | 4 |
| E. P. Roe, | 25 | B | May 2, | June 5, | July 2, | 4 | 5 | 3-4 | 1 | 1 |
| Ernest, | 61 | P | May 12, | June 7, | July 2, | ...... | 4 | 2-3 | 10 | 8 |
| Eureka, | 18 | P | May 14, | June 11, | July 9, | 4 | 5 | 5-6 | 5 | 8 |
| Farnsworth, | 37 | B | May 12, | June 7, | June 29, | 2 | 2 | 7-8 | 9 | 10 |
| Gandy, | 17 | B | May 16, | June 11, | July 9, | 3 | 5 | 2-3 | 5 | 9 |
| Gov. Hoard, | 11 | B | May 3, | June 6, | July 2, | 2 | 4 | 2-3 | 5 | 8 |
| Greenville, | 4 | P | May 8, | June 6, | July 5, | 5 | 6 | 3-4 | 8 | 10 |
| Harrison, | 54 | P | May 12, | June 7, | July 2, | 4 | 3 | 7-8 | 7 | 8 |
| Hay's Prolific, | 48 | B | May 12, | June 7, | June 27, | 2 | 3 | 2-3 | 6 | 7 |
| Haverland, | 32 | P | May 8, | June 8, | July 9, | 4 | 7 | 5-6 | 5 | 9 |
| Henderson, | 31 | P | May 8, | June 5, | July 9, | 5 | 6 | 3-4 | 6 | 10 |
| Henderson No. 12, | 62 | B | May 10, | June 8, | July 5, | ...... | 6 | 2-3 | 10 | 8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hull's No. 3, | 58 | B | May 3, | June 12, | June 27, | | 2 | 8-9 | 7 | 6 |
| Hunn, | 59 | P | May 17, | June 14, | July 9, | | 2 | 5-6 | 6 | 9 |
| H. W. Beecher, | 42 | B | May 14, | June 7, | July 2, | 4 | 3 | 2-3 | 8 | 7 |
| Iowa Beauty, | 40 | B | May 9, | June 7, | July 2, | 1 | 2 | 5-6 | 9 | 8 |
| Kentucky, | 10 | B | May 13, | June 3, | July 5, | 3 | 3 | 5-6 | 6 | 6 |
| Leader, | 19 | B | May 10, | June 4, | July 2, | 2 | 4 | 8-9 | 5 | 7 |
| Luther, | 21 | B | May 7, | June 4, | June 29, | 3 | 5 | 10 | 4 | 5 |
| Maida No. 11860, | 57 | B | May 13, | June 11, | June 29, | 3 | 3 | 3-4 | 7 | 9 |
| Margaret, | 44 | B | May 8, | June 7, | July 5, | 2 | 4 | 7-8 | 7 | 8 |
| Mary, | 39 | P | May 14, | June 10, | July 2, | 2 | 4 | 7-8 | 9 | 10 |
| Meek's Early, | 6 | B | April 30, | June 3, | June 27, | 3 | 3 | 3-4 | 7 | 6 |
| Monarch, | 1 | B | May 2, | June 5, | July 5, | 3 | 6 | 7-8 | 4 | 8 |
| Mt. Joy, | 20 | B | May 10, | June 7, | July 9, | 4 | 6 | 7-8 | 8 | 10 |
| Mt. Vernon, | 7 | B | May 2, | June 4, | July 5, | 3 | 5 | 5-6 | 6 | 7 |
| Nan, | 33 | B | May 8, | June 10, | July 2, | 1 | 3 | 7-8 | 10 | 9 |
| Ohio Centennial, | 29 | B | May 8, | June 10, | July 9, | 3 | 7 | 2-3 | 6 | 10 |
| Parker Earle, | 32 | B | May 13, | June 10, | July 9, | 5 | 5 | 2-3 | 3 | 5 |
| Perkins No. 1, | 43 | P | May 14, | June 10, | July 5, | 3 | 3 | 5-6 | 5 | 7 |
| Quality, | 50 | B | May 16, | June 13, | June 27, | 1 | 3 | 5-6 | 7 | 8 |
| Riehl's No. 25, | 63 | B | May 15, | June 10, | July 9, | | 6 | 5-6 | 7 | 9 |
| Riehl's No. 26, | 64 | B | May 15, | June 7, | June 27, | | 6 | 5-6 | 7 | 8 |
| Riehl's No. 27, | 65 | B | May 14, | June 7, | June 27, | | 4 | 5-6 | 6 | 6 |
| Riehl's No. 28, | 66 | B | May 16, | June 7, | June 27, | | 4 | 5-6 | 6 | 6 |
| Sample, | 60 | P | May 14, | June 6, | July 2, | | 3 | 3-4 | 10 | 8 |
| See No. 2, | 22 | P | May 2, | June 5, | July 2, | 5 | 6 | 3-4 | 6 | 9 |
| See No. 3, | 45 | P | June 15, | June 11, | July 5, | 4 | 4 | 5-6 | 4 | 5 |
| See No. 4, | 46 | P | May 12, | June 10, | July 5, | 3 | 5 | 3-4 | 5 | 6 |
| See No. 5, | 47 | P | May 12, | June 9, | July 5, | 6 | 7 | 3-4 | 6 | 7 |
| Shuster's Gem, | 5 | P | May 3, | June 5, | July 5, | 4 | 6 | 7-8 | 8 | 10 |
| Smeltzer's Early, | 37 | B | May 8, | June 4, | June 29, | 3 | 4 | 5-6 | 7 | 10 |
| Stevens, | 36 | B | May 3, | June 5, | July 2, | 3 | 5 | 3-4 | 4 | 5 |
| Townsend, | 38 | P | May 15, | June 10, | July 3, | 4 | 5 | 2-3 | 8 | 7 |
| Van Deman, | 12 | B | May 7, | June 6, | July 2, | 4 | 6 | 5-6 | 5 | 7 |
| Warfield, | 35 | P | May 3, | June 6, | July 2, | 5 | 3 | 3-4 | 5 | 9 |
| West Lawn, | 34 | P | May 7, | June 4, | July 2, | 4 | 5 | 2-3 | 5 | 9 |
| Wilson, | 9 | B | May 1, | June 5, | June 29, | 2 | 3 | 10 | 3 | 7 |

### *Length of Fruit Season, Yield of 30 Feet of Matted Row, 20 Hills (30 feet), and Average Weight of Berries.*

| Name. | Plot No. | A. Hills. B. Mat. | First Picking. | Last Picking. | Crop in grams. | Average weight of berry. | Difference in favor of— | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | A. | B. |
| Adam's Favorite, | | A | June 9, | June 25, | 1,353 | 4.45 | .61 | ........... |
| | 51 | B | June 9, | June 25, | 1,270 | 3.84 | ........... | ........... |
| Banquet, | | A | June 8, | July 5, | 1,710 | 2.12 | ........... | ........... |
| | 14 | B | June 6, | July 5, | 2,970 | 3.28 | ........... | 1.16 |
| Beebe, | | A | June 9, | July 5, | 2,150 | 5.77 | ........... | ........... |
| | 16 | B | June 9, | July 5, | 2,955 | 7.19 | ........... | 1.42 |
| Boynton, | | A | June 8, | July 2, | 4,940 | 3.34 | .72 | ........... |
| | 26 | B | June 8, | June 29, | 5,135 | 2.62 | ........... | ........... |
| Brandywine, | | A | June 11, | July 9, | 6,363 | 9.91 | .10 | ........... |
| | 23 | B | June 12, | July 9, | 8,485 | 9.81 | ........... | ........... |
| Bryant, | | A | June. | | | | | |
| | 56 | B | June 11, | July 2, | 2,555 | 6.18 | ........... | ........... |
| Bubach No. 5, | | A | June 4, | June 25, | 2,563 | 1.78 | ........... | ........... |
| | 13 | B | June 4, | June 27, | 5,525 | 2.20 | ........... | .42 |
| Carrie, | | A | June 9, | June 25, | 1,081 | 3.07 | ........... | ........... |
| | 52 | B | June 8, | June 27, | 1,836 | 4.45 | ........... | 1.38 |
| Champion, | | A | June 9, | July 2, | 1,860 | 7.85 | .46 | ........... |
| | 49 | B | June 11, | July 2, | 2,470 | 7.39 | ........... | ........... |
| Chas. Downing, | | A | June 8, | July 5, | 2,700 | 4.20 | ........... | ........... |
| | 2 | B | June 11, | July 5, | 3,545 | 5.42 | ........... | 1.22 |
| Crawford, | | A | June 8, | July 9, | 6,111 | 2.80 | .05 | ........... |
| | 30 | B | June 8, | July 5, | 7,090 | 2.75 | ........... | ........... |
| Crescent, | | A | June 6, | July 2, | 5,220 | 2.56 | .08 | ........... |
| | 3 | B | June 6, | July 2, | 3,223 | 2.48 | ........... | ........... |
| Cumberland, | | A | June 8, | July 5, | 2,290 | 4.69 | ........... | ........... |
| | 8 | B | June 8, | July 5, | 3,772 | 4.77 | ........... | .08 |
| Darling, | | A | June. | | | | | |
| | 55 | B | June 4, | June 27, | 2,495 | 3.98 | ........... | ........... |
| Dayton, | | A | June 9, | July 5, | 4,994 | 5.84 | ........... | ........... |
| | 41 | B | June 9, | July 5, | 5,550 | 6.45 | ........... | .61 |
| Ella, | | A | June 4, | June 27, | 2,822 | 2.69 | ........... | ........... |
| | 53 | B | June 4, | June 27, | 2,120 | 2.82 | ........... | 1.13 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Enhance, | 34 | A | June 8, | July 2, | 3,378 | 4.58 | 1.72 | |
| | | B | June 8, | July 2, | 4,390 | 2.86 | | |
| E. P. Roe, | 25 | A | June 6, | June 29, | 3,364 | 3.29 | | |
| | | B | June 6, | July 2, | 4,680 | 4.25 | | .96 |
| Ernest, | 61 | A | June. | | | | | |
| | | B | June 8, | July 2, | 3,685 | 3.58 | | |
| Eureka, | 18 | A | June 11, | July 9, | 3,828 | 5.96 | 1.28 | |
| | | B | June 12, | July 9, | 4,060 | 7.67 | | |
| Farnsworth, | 37 | A | June 8, | June 29, | 1,143 | 2.32 | | |
| | | B | June 8, | June 29, | 1,642 | 2.88 | | .56 |
| Gandy, | 17 | A | June 15, | July 9, | 2,800 | 6.21 | | |
| | | B | June 11, | July 9, | 4,170 | 3.00 | | 1.79 |
| Gov. Hoard, | 11 | A | June 8, | July 2, | 1,649 | 3.65 | .11 | |
| | | B | June 8, | July 2, | 3,710 | 3.54 | | |
| Greenville, | 4 | A | June 8, | July 5, | 4,174 | 4.37 | | |
| | | B | June 8, | July 2, | 5,270 | 5.32 | | .96 |
| Harrison, | 54 | A | June 8, | July 2, | 3,065 | 3.33 | | |
| | | B | June 8, | July 2, | 2,725 | 4.47 | | 1.15 |
| Hay's Prolific, | 48 | A | June 8, | June 27, | 1,317 | 2.76 | | |
| | | B | June 8, | June 27, | 2,781 | 2.85 | | .09 |
| Haverland, | 32 | A | June 9, | July 5, | 3,500 | 5.27 | | |
| | | B | June 9, | July 9, | 6,480 | 6.42 | | 1.15 |
| Henderson, | 31 | A | June 8, | July 5, | 4,767 | 2.66 | | |
| | | B | June 8, | July 9, | 5,570 | 3.10 | | .44 |
| Henderson No. 12, | 62 | A | June. | | | | | |
| | | B | June 9, | July 5, | 5,906 | 6.32 | | |
| Hull's No. 8, | 58 | A | June. | | | | | |
| | | B | June 13, | June 27, | 1,451 | 6.34 | | |
| Hunn, | 59 | A | June. | | | | | |
| | | B | June 15, | July 9, | 1,663 | 6.37 | | |
| H. W. Beecher, | 42 | A | June 8, | July 2, | 3,423 | 5.61 | .06 | |
| | | B | June 9, | July 2, | 2,925 | 5.53 | | |
| Iowa Beauty, | 40 | A | June 8, | June 25, | 600 | 4.35 | | |
| | | B | June 8, | June 29, | 2,000 | 6.88 | | 2.53 |
| Kentucky, | 10 | A | June 9, | July 5, | 2,250 | 4.13 | | |
| | | B | June 9, | July 5, | 3,505 | 4.22 | | .09 |
| Leader, | 19 | A | June 4, | June 29, | 1,560 | 3.96 | | |
| | | B | June 9, | July 2, | 3,314 | 6.29 | | 2.32 |
| Luther, | 21 | A | June 4, | June 25, | 2,970 | 2.41 | .29 | |
| | | B | June 4, | June 29, | 4,419 | 2.02 | | |
| Maida No. 11860, | 57 | A | June 11, | June 29, | 3,572 | 5.74 | | |
| | | B | June 11, | July 2, | 2,306 | 7.32 | | 1.59 |

## *Length of Fruit Season, Etc.—Continued.*

| Name. | Plot No. | A. Hills. B. Mat. | First Picking. | Last Picking. | Crop in grams. | Average weight of berry. | Difference in favor of— A. | Difference in favor of— B. |
|---|---|---|---|---|---|---|---|---|
| Margaret, |  | A | June 3, | July 5, | 1,120 | 5.22 |  |  |
|  | 44 | B | June 3, | July 5, | 3,321 | 6.84 |  | 1.62 |
| Mary, |  | A | June 15, | June 29, | 1,700 | 7.14 |  |  |
|  | 29 | B | June 11, | July 2, | 3,631 | 9.72 |  | 2.58 |
| Meek's Early, |  | A | June 4, | June 27, | 2,140 | 2.64 |  |  |
|  | 6 | B | June 4, | June 27, | 2,755 | 3.15 |  | .51 |
| Monarch, |  | A | June 6, | July 5, | 2,506 | 3.33 |  |  |
|  | 1 | B | June 8, | July 5, | 5,040 | 4.44 |  | 1.11 |
| Mt. Joy, |  | A | June 8, | July 9, | 3,017 | 5.40 |  |  |
|  | 20 | B | June 8, | July 9, | 5,405 | 8.02 |  | 2.62 |
| Mt. Vernon, |  | A | June 4, | July 5, | 2,632 | 2.73 | .69 |  |
|  | 7 | B | June 4, | July 2, | 4,585 | 2.04 |  |  |
| Nan, |  | A | June 12, | July 2, | 967 | 6.55 | .13 |  |
|  | 32 | B | June 11, | July 2, | 3,188 | 6.42 |  |  |
| Ohio Centennial, |  | A | June 13, | July 9, | 2,747 | 7.41 |  |  |
|  | 20 | B | June 11, | July 9, | 6,645 | 11.16 |  | 3.65 |
| Parker Earle, |  | A | June 11, | July 9, | 4,540 | 7.64 |  |  |
|  | 33 | B | June 11, | July 9, | 4,490 | 8.58 |  | .94 |
| Perkin's No. 1, |  | A | June 12, | July 5, | 1,133 | 5.90 |  |  |
|  | 43 | B | June 11, | July 5, | 3,790 | 8.73 |  | 2.83 |
| Quality, |  | A | June 15, | June 23, | 700 | 5.71 | 1.12 |  |
|  | 50 | B | June 13, | June 27, | 1,203 | 4.59 |  |  |
| Riehl's No. 26, |  | A | June. |  |  |  |  |  |
|  | 63 | B | June 11, | July 9, | 5,119 | 10.67 |  |  |
| Riehl's No. 26, |  | A | June. |  |  |  |  |  |
|  | 64 | B | June 8, | June 27, | 5,626 | 6.23 |  |  |
| Riehl's No. 27, |  | A | June. |  |  |  |  |  |
|  | 65 | B | June 3, | June 27, | 3,240 | 2.92 |  |  |
| Riehl's No. 28, |  | A | June. |  |  |  |  |  |
|  | 66 | B | June 8, | June 27, | 3,735 | 4.76 |  |  |
| Sample, |  | A | June. |  |  |  |  |  |
|  | 60 | B | June 6, | July 2, | 2,057 | 6.08 |  |  |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| See No. 2, | | A | June 8, | July 2, | 4,028 | 3.97 | ............ | ............ |
| | 22 | B | June 8. | July 2, | 5,500 | 4.90 | ............ | .32 |
| See No. 3, | | A | June 11, | July 5, | 3,780 | 6.77 | ............ | ............ |
| | 45 | B | June 12, | July 5, | 3,068 | 6.91 | ............ | .14 |
| See No. 4, | | A | June 11, | July 5, | 2,700 | 6.02 | ............ | ............ |
| | 46 | B | June 11, | July 5, | 4,230 | 6.08 | ............ | .01 |
| See No. 5, | | A | June 9, | July 5, | 5,365 | 4.49 | ............ | ............ |
| | 47 | B | June 9, | July 5, | 6,530 | 6.06 | ............ | 1.57 |
| Shuster's Gem, | | A | June 8, | July 5, | 3,844 | 3.06 | ............ | ............ |
| | 5 | B | June 8, | July 5, | 5,365 | 3.18 | ............ | .12 |
| Smeltzer's Early, | | A | June 4, | June 27, | 2,700 | 5.00 | 2.70 | ............ |
| | 27 | B | June 6, | June 29, | 3,770 | 2.30 | ............ | ............ |
| Stevens, | | A | June 6, | June 27, | 2,920 | 2.22 | ............ | ............ |
| | 36 | B | June 6, | July 2, | 4,740 | 2.24 | ............ | .03 |
| Townsend, | | A | June 11, | June 29, | 3,698 | 6.16 | ............ | ............ |
| | 28 | B | June 11, | July 2, | 4,095 | 6.90 | ............ | .74 |
| Van Deman, | | A | June 6, | July 2, | 3,753 | 2.99 | .05 | ............ |
| | 12 | B | June 6, | June 29, | 5,135 | 2.94 | ............ | ............ |
| Warfield, | | A | June 8, | July 2, | 4,853 | 4.06 | .12 | ............ |
| | 35 | B | June 8, | June 29, | 7,350 | 3.96 | ............ | ............ |
| West Lawn, | | A | June 6, | July 2, | 3,214 | 4.98 | .26 | ............ |
| | 34 | B | June 8, | June 29, | 4,645 | 4.67 | ............ | ............ |
| Wilson, | | A | June 8, | June 29, | 1,333 | 1.98 | .14 | ............ |
| | 9 | B | June 6, | June 27, | 2,718 | 1.79 | ............ | ............ |

From these tables it will be seen that the fruiting period extended from June 4 to July 9, or 5 weeks. The earliest varieties were Meek's Early and Ella, and the latest variety was Hunn. The five best varieties in point of yield in the matted row were Brandywine, Warfield, Crawford, Ohio Centennial and See No. 5.

The five best varieties in point of yield in hills were Crawford, See No. 5, Brandywine, Crescent and Dayton, in the order named.

The five best varieties in point of average sized berries by the matted row system were Ohio Centennial, Riehl's No. 25, Brandywine, Eureka, Champion, Parker Earle, Ohio Centennial and Mary.

The comparison of the two systems of culture in regard to their value in producing berries of large size has been continued as is seen in the above tables. The results this year seem to show a decided increase in favor of the mat. In the case of nineteen of the varieties grown by both systems, there was a difference varying from .05 grams to 2.70 grams in favor of the hill system. In the case of the remaining thirty-five varieties the difference was much greater and varied from .01 gram to 3.65 grams.

The following tables give the average yield of all varieties having fruited for two or more years in the matted row and hills. By taking a general glance at them, it will be seen that the average yield of each in the matted row is about 3,000 grams greater than the same variety in hills. Consequently as both occupy the same number of square feet, the difference in the size of the berry would have to be very decided indeed to make up for the loss of the 80 bushels of ordinary sized fruit which the 3,000 grams above mentioned represents. It would seem that the hill system might be well adapted to a small place while utterly unsuitable for a large one.

## *Average Yield of Varieties in Hills, for Two, Three or Four Years; 20 Hills Equals 30 Feet of Row; Weight in Grams.*

| Name. | 1896. | 1897. | 1899. | 1900. | Average yield. | No. of yrs. |
|---|---|---|---|---|---|---|
| *1. Warfield, | 5,940 | 7,400 | 7,495 | 4,853 | 6,422 | 4 |
| 2. Henderson, | 4,675 | 7,670 | 4,625 | 4,767 | 5,434 | 4 |
| 3. Crawford, | 2,980 | 5,995 | 5,285 | 6,111 | 5,093 | 4 |
| 4. Crescent, | 3,285 | 6,680 | 4,545 | 5,220 | 4,933 | 4 |
| 5. Haverland, | 5,540 | 6,030 | 4,060 | 3,500 | 4,783 | 4 |
| 6. Greenville, | 5,455 | 5,250 | 3,265 | 4,174 | 4,536 | 4 |
| 7. Parker Earle, | 5,180 | 4,095 | 3,835 | 4,540 | 4,413 | 4 |
| 8. Brandywine, | 2,030 | 4,240 | 5,995 | 5,363 | 4,407 | 4 |
| 9. See No. 5, | .......... | .......... | 3,440 | 5,365 | 4,403 | 2 |
| 10. See No. 2, | 3,530 | 5,270 | 4,505 | 4,028 | 4,333 | 4 |
| 11. Van Deman, | 3,610 | 3,745 | 6,105 | 3,753 | 4,303 | 4 |
| 12. Boynton, | 4,455 | 5,230 | 2,400 | 4,940 | 4,256 | 4 |
| 13. Shuster's Gem, | 3,535 | 5,595 | 3,935 | 3,844 | 4,227 | 4 |
| 14. Harrison, | .......... | .......... | 4,400 | 3,085 | 3,743 | 2 |
| 15. Dayton, | 2,110 | 3,835 | 3,395 | 4,994 | 3,584 | 4 |
| 16. Townsend, | 3,145 | 3,295 | 3,965 | 3,693 | 3,525 | 4 |
| 17. Ella, | .......... | .......... | 4,210 | 2,822 | 3,516 | 2 |
| 18. Eureka, | 2,662 | 3,720 | 3,105 | 3,828 | 3,329 | 4 |
| 19. Enhance, | 2,786 | 3,270 | 3,920 | 3,273 | 3,312 | 4 |
| 20. See No. 4, | .......... | .......... | 3,765 | 2,700 | 3,233 | 2 |
| 21. West Lawn, | 1,440 | 4,605 | 3,385 | 3,314 | 3,186 | 4 |
| 22. Michel's Early, | 1,615 | 4,650 | .......... | .......... | 3,133 | 2 |
| 23. See No. 3, | .......... | .......... | 2,480 | 3,780 | 3,130 | 2 |
| 24. Luther, | 2,445 | 6,045 | 1,030 | 2,970 | 3,123 | 4 |
| 25. E. P. Roe, | 2,225 | 2,810 | 3,210 | 3,364 | 2,902 | 4 |
| 26. Wilson, | 4,260 | 4,795 | 557 | 1,333 | 2,736 | 4 |
| 27. Mt. Joy, | 2,642 | 4,040 | 1,110 | 3,017 | 2,702 | 4 |
| 28. Ohio Centennial, | 1,505 | 2,980 | 3,185 | 2,747 | 2,604 | 4 |
| 29. Beebe, | 2,395 | 2,790 | 3,000 | 2,150 | 2,584 | 4 |
| 30. Bubach, | 1,285 | 4,670 | 1,810 | 2,563 | 2,582 | 4 |
| 31. Farnsworth, | 2,830 | 5,135 | 645 | 1,143 | 2,438 | 4 |
| 32. Stevens, | 760 | 3,155 | 2,735 | 2,920 | 2,392 | 4 |
| 33. Gov. Hoard, | 3,600 | 2,615 | 1,330 | 1,642 | 2,297 | 4 |
| 34. Banquet, | 2,440 | 3,615 | 1,395 | 1,710 | 2,280 | 4 |
| 35. Mt. Vernon, | 2,265 | 2,965 | 1,180 | 2,632 | 2,261 | 4 |
| 36. Gandy, | 1,900 | 2,365 | 1,490 | 2,800 | 2,139 | 4 |
| 37. Kentucky, | 2,110 | 3,005 | 1,115 | 2,250 | 2,120 | 4 |
| 38. Monarch, | 1,247 | 3,330 | 1,070 | 2,565 | 2,053 | 4 |
| 39. Smeltzer's Early, | 1,235 | 3,110 | 1,158 | 2,700 | 2,051 | 4 |
| 40. Nan, | 2,695 | 3,775 | 635 | 967 | 2,018 | 4 |
| 41. Champion, | .......... | .......... | 2,160 | 1,860 | 2,010 | 2 |
| 42. Cumberland, | 2,305 | 2,440 | 900 | 2,290 | 1,984 | 4 |
| 43. Adam's Favorite, | .......... | .......... | 2,515 | 1,353 | 1,934 | 2 |
| 44. Maida No. 11860, | .......... | .......... | 1,115 | 2,573 | 1,844 | 2 |
| 45. Chas Downing, | 1,525 | 2,245 | 895 | 2,700 | 1,841 | 4 |
| 46. H. W. Beecher, | 685 | 1,230 | 2,015 | 3,433 | 1,841 | 4 |
| 47. Carrie, | .......... | .......... | 2,350 | 1,031 | 1,691 | 2 |
| 48. Leader, | 1,270 | 2,355 | 960 | 1,560 | 1,536 | 4 |
| 49. Hay's Prolific, | .......... | .......... | 1,215 | 1,817 | 1,516 | 2 |
| 50. Meek's Early, | 705 | 1,575 | 1,240 | 2,140 | 1,415 | 4 |
| 51. Mary, | .......... | .......... | 709 | 1,700 | 1,245 | 2 |
| 52. Perkins No. 1, | .......... | .......... | 1,035 | 1,138 | 1,087 | 2 |
| 53. Margaret, | .......... | .......... | 725 | 1,120 | 923 | 2 |
| 54. Iowa Beauty, | .......... | .......... | 1,010 | 600 | 805 | 2 |
| 55. Quality, | .......... | .......... | 96 | 700 | 398 | 2 |

*Numbers refer to position of varieties in this table only.

## *Average Yield of Varieties in "Matted Row" for Two, Three or Four Years; Rows 30 Feet in Length; Weight in Grams.*

| Name. | 1896. | 1897.. | 1899. | 1900. | Average yield. | No. of yrs. |
|---|---|---|---|---|---|---|
| *1. Warfield, | 7,465 | 10,780 | 11,685 | 7,350 | 9,320 | 4 |
| 2. Crawford, | 10,475 | 9,140 | 7,705 | 7,090 | 8,603 | 4 |
| 3. Henderson, | 6,928 | 10,620 | 7,195 | 5,570 | 7,578 | 4 |
| 4. Mary, | 9,562 | 12,595 | 3,375 | 3,681 | 7,303 | 4 |
| 5. Shuster's Gem, | 8,815 | 8,420 | 5,390 | 6,265 | 7,223 | 4 |
| 6. Haverland, | 7,060 | 7,895 | 6,570 | 6,480 | 7,001 | 4 |
| 7. Brandywine, | 2,750 | 7,805 | 8,960 | 8,485 | 7,000 | 4 |
| 8. See No. 2, | 6,420 | 7,740 | 7,945 | 5,500 | 6,901 | 4 |
| 9. Parker Earle, | 8,637 | 9,095 | 4,295 | 4,490 | 6,629 | 4 |
| 10. Townsend, | 7,256 | 8,015 | 6,390 | 4,095 | 6,439 | 4 |
| 11. Enhance, | 6,465 | 8,040 | 6,265 | 4,390 | 6,290 | 4 |
| 12. Crescent, | 4,485 | 10,570 | 6,690 | 3,223 | 6,242 | 4 |
| 13. Michel's Early, | 4,420 | 7,965 | .......... | .......... | 6,193 | 2 |
| 14. See No. 4, | 4,941 | 8,561 | 6,640 | 4,330 | 6,119 | 4 |
| 15. Bubach, | 9,955 | 8,015 | 820 | 5,525 | 6,079 | 4 |
| 16. Mt. Joy, | 6,905 | 8,615 | 3,190 | 5,465 | 6,044 | 4 |
| 17. Ohio Centennial, | 2,330 | 8,775 | 6,385 | 6,645 | 6,034 | 4 |
| 18. Boynton, | 5,085 | 10,265 | 3,575 | 5,135 | 6,015 | 4 |
| 19. Monarch, | 9,265 | 7,360 | 1,970 | 5,040 | 5,909 | 4 |
| 20. West Lawn, | 6,940 | 9,345 | 2,395 | 4,645 | 5,831 | 4 |
| 21. Eureka, | 3,340 | 7,860 | 4,010 | 4,060 | 5,815 | 4 |
| 22. See No. 5, | 2,790 | 8,760 | 5,010 | 6,530 | 5,772 | 4 |
| 23. Greenville, | 6,870 | 7,645 | 3,165 | 5,270 | 5,738 | 4 |
| 24. Van Deman, | 2,725 | 7,460 | 7,210 | 5,135 | 5,633 | 4 |
| 25. Luther, | 5,600 | 9,825 | 2,545 | 4,419 | 5,597 | 4 |
| 26. Mt. Vernon, | 8,025 | 8,575 | 9,090 | 4,585 | 5,544 | 4 |
| 27. Leader, | 8,540 | 8,040 | 1,770 | 3,314 | 5,416 | 4 |
| 28. Banquet, | 6,975 | 8,370 | 2,980 | 2,970 | 5,324 | 4 |
| 29. Iowa Beauty, | 6,100 | 8,350 | 2,735 | 2,000 | 5,296 | 4 |
| 30. E. P. Roe, | 4,175 | 6,535 | 5,310 | 4,680 | 5,175 | 4 |
| 31. Dayton, | 3,585 | 5,880 | 5,535 | 5,550 | 5,138 | 4 |
| 32. Farnsworth, | 8,028 | 8,910 | 8,085 | 1,642 | 4,866 | 4 |
| 33. Henderson No. 12, | .......... | .......... | 3,495 | 5,905 | 4,700 | 2 |
| 34. See No. 3, | 2,196 | 8,678 | 4,485 | 3,058 | 4,604 | 4 |
| 35. Stevens, | 4,745 | 5,735 | 2,970 | 4,740 | 4,548 | 4 |
| 36. Cumberland, | 5,810 | 7,275 | 1,565 | 2,772 | 4,355 | 4 |
| 37. Gov. Hoard, | 4,652 | 5,585 | 2,900 | 3,710 | 4,212 | 4 |
| 38. Adam's Favorite, | .......... | 7,618 | 3,670 | 1,270 | 4,186 | 3 |
| 39. Smeltzer's Early, | 4,255 | 5,435 | 3,190 | 3,770 | 4,163 | 4 |
| 40. Perkin's No. 1, | 2,424 | 9,050 | 2,060 | 2,790 | 4,086 | 4 |
| 41. Gandy, | 2,960 | 5,510 | 3,630 | 4,170 | 4,068 | 4 |
| 42. Ernest, | .......... | .......... | 3,025 | 3,685 | 3,355 | 2 |
| 43. Beebe, | 3,725 | 3,425 | 3,140 | 2,955 | 3,336 | 4 |
| 44. Wilson, | 3,135 | 3,640 | 1,015 | 2,718 | 3,302 | 4 |
| 45. Ella, | .......... | .......... | 4,250 | 2,120 | 3,185 | 2 |
| 46. Kentucky, | 3,337 | 4,155 | 2,575 | 2,506 | 3,163 | 4 |
| 47. Harrison, | .......... | .......... | 3,480 | 2,735 | 3,108 | 2 |
| 48. H. W. Beecher, | 1,750 | 4,805 | 2,000 | 2,925 | 2,870 | 4 |
| 49. Maida No. 11860, | .......... | 3,951 | 2,200 | 2,306 | 2,819 | 3 |
| 50. Champion, | .......... | 4,185 | 1,975 | 2,470 | 2,677 | 3 |
| 51. Nan, | 1,910 | 5,375 | 1,215 | 2,188 | 2,672 | 4 |
| 52. Margaret, | 3,245 | 2,330 | 1,580 | 3,321 | 2,619 | 4 |
| 53. Bryant, | .......... | .......... | 4,110 | 2,555 | 2,483 | 2 |
| 54. Chas. Downing, | 1,340 | 3,225 | 1,680 | 3,545 | 2,448 | 4 |
| 55. Sample, | .......... | .......... | 1,920 | 2,657 | 2,289 | 2 |
| 56. Hay's Prolific, | .......... | 2,403 | 1,600 | 2,781 | 1,928 | 3 |
| 57. Meek's Early, | 655 | 2,155 | 1,802 | 2,755 | 1,842 | 4 |
| 58. Carrie, | .......... | 310 | 2,900 | 1,836 | 1,682 | 3 |
| 59. Darling, | .......... | .......... | 795 | 2,495 | 1,645 | 2 |
| 60. Hull's No. 3, | .......... | 2,322 | 1,000 | 1,451 | 1,591 | 3 |
| 61. Quality, | .......... | 1,825 | 400 | 1,202 | 1,142 | 3 |

*Numbers refer to position of varieties in this table only.

## NOTES ON VARIETIES.

In the following list more particular mention is made of some of the best varieties grown here and also of the newer varieties sent here for trial and report.

*Adams' Favorite.*—Received from Solomon Adams, Tamaqua, Schuylkill county, Pa., in the spring of 1896. In growth it is quite vigorous, forming a mat very freely and quickly. Flowers pistillate; berry red, conical, blunt at the apex, flesh firm and acid. The yield for this season was quite poor, while the average size of the berries was some better than heretofore.

*Brandywine.*—Sent here for trial in 1893 by Edward T. Ingram, West Chester, Pa. Bisexual. Berries of large size, fine color, shape and flavor, and solid. In the average yield tables above, it will be found to rank seventh and eighth respectively for the matted row and hill systems. One of the best late to very late varieties grown here and of value as a market variety.

*Bryant.* –Received from Birdseye & Son, Hopewell, New York, in the spring of 1898. Flowers perfect, berry blunt, conical, dark red, many seeded, and solid. The average size is large but the yield has been poor, averaging for the two years it has been tried here, but 2,483 grams, or about 60 bushels per acre. Grown in matted row only so far.

*Carrie.*—Received from Thompson's Sons, Rio Vista, Va., in 1897. Flowers pistillate, berry bright red, long, conical, with a smooth neck under the calyx, and inclined to be irregular. The average size was good, while the yield was very poor this year, it being at a rate of less than 50 bushels to the acre by the hill system, and a trifle smaller by the matted row.

*Champion.*—Received in 1895 from David Strouse, Royersford, Pa., Flowers pistillate, foliage large and vigorous, berries large to very large, conical, irregular, being ribbed longitudinally, soft, bright red in color, seeds deeply set. Flavor sub-acid. The average yield is at the rate of very little over 65 bushels per acre.

*Crawford.*—A very good variety having perfect flowers. Growth very vigorous, matting quite freely. It has been grown here for the last six years at least. The average yield for the last four being 8,603 grams for the matted row and 5,093 grams for the hill system. Berries medium in size.

*Darling.*—Received from Thompson's Sons, Rio Vista, Va., in 1897. This is a perfect flowered variety. Berry round, conical, bright red, seeds few and deeply set, soft and very small. It has been grown entirely in the matted row and shows an average yield of only 1,645 grams or at the rate of about 40 bushels per acre. Mats with little freedom and only moderately vigorous. Will be discarded.

*Ella.*—Received from O. D. Schock, Hamburg, Pa., in 1896. A bisexual flowered variety of extreme earliness, rivaling Meek's Early in this particular, but much better in yield and length of fruiting season. The leaves are of medium size and borne on long stems. The berry is conical, regular, bright red in color, solid, and has a good flavor. Seeds few and deeply set. The average size is good and a trifle better than Meek's Early, while in yield it is much better, the average in hills being 3,516 grams or at the rate of 90 bushels per acre. That for Meek's Early was but 1,415 grams. In the matted row it yielded an average of 3,185 grams while Meek's Early had but 1,842 grams to its credit.

*Earnest.*—Received from Robert E. Rodgers, Snyder Creek, Venango county, Pa., in 1898. A midseason, pistillate variety which is quite vigorous, mats with great freedom and has been little affected by leaf blight so far. The berry is flat, conical, and compressed back of apex, forming a sort of inverted pear shaped fruit. It is bright red in color, firm, possesses a good flavor and has numerous seeds. The average yield for two years, during which time it has been on trial here, is 3,355 grams, or at the rate of about 87 bushels per acre.

*Eureka.*—An old pistillate variety producing very large berries and large yields. It ranks eighteenth in size of yield produced by the hills and twenty-first as produced by the matted row.

*Gandy.*—This is one of the standard late to very late varieties grown here. Its flowers are bisexual and its berries large, fine and solid. It is very vigorous, yet mats with only moderate freedom and is very little affected by leaf blight. Grown in the matted row, its rate of yield is just about 100 bushels per acre while in hills it is but about one-half as much.

*Harrison.*—Received from Geo. W. Adams, Tamaqua, Schuylkill county, Pa., in 1897. A pistillate variety of great vigor and which mats with freedom but has been badly affected by leaf blight. Berry red, conical, blunt at the apex, and has few seeds. Yield not quite large enough to be satisfactory.

*Hay's Prolific.*—Received from Rodgers Nursery Co., Moorestown, N. J., in the spring of 1896 A perfect flowered variety of strong yet not vigorous growth. It has not succeeded here and will be discarded.

*Henderson.*—A very vigorous, perfect flowered variety which gives uniformly large yields by both systems of culture. Berry of medium size, good flavor, and quite firm. Grown in hills the average yield for the last four years is 5,434 grams, which is the second largest of all. In the matted row for the same number of years it yielded 7,578 grams, which is the third largest of all.

*Henderson No. 12.*—Received from Peter Henderson & Co., New

York, N. Y., in 1898. This is a vigorous growing variety which mats with very great freedom, and is quite free from blight. Its flowers are perfect. Berry conical, slightly irregular, has a good, bright red color, many seeded and firm. Having an average yield of 4,700 grams for the two years it has been grown here, it may be considered a fairly good yielding variety. It is a mid-season variety.

*Hull's No. 3.*—Received from E. J. Hull, Olyphant, Pa., in 1895. A perfect flowered variety, moderate in vigor and freedom of matting, and which has been very badly affected by leaf blight. Its yields have always been poor and it will be discarded.

*Hunn.*—Received from Birdseye & Son, Hopewell, N. Y., in 1898. Owing to an error in transcribing the report this variety was described last year as having "perfect" flowers and "bright red" berries, while in fact the flowers are pistillate and the berries are dark red. On account of similar errors, "Carrie" and "Ernest" were reported as having perfect flowers while they are really pistillate. While very vigorous this variety mats with only moderate freedom and has been affected by leaf blight to a considerable degree. Berry abruptly conical, solid and possesses a good flavor. Leaves very vigorous and borne on short stems. Season very late. The yield has been very small so far. As it was placed under almost the same condition as Sample, it may do a great deal better in this respect in the new bed, yet if it does not, this fact will not weigh so much against it on account of the extreme lateness of its fruiting season.

*H. W. Beecher.*—Flowers bisexual. Vigorous in growth and matting with freedom, this variety has yielded an average of only 2,870 grams for the last four years. It will be discarded.

*Maida No. 11860.*—This variety was received from Prof. Heiges, Washington, D. C., in 1896. A bisexual flowered variety of vigorous growth, matting with moderate freedom and resisting leaf blight well. Berry large, inverted pear shaped, bright red in color; seeds many and flesh soft. The yield has been poor, the average from the matted row for four years being 2,819 grams, and from the hills 1,844 grams.

*Margaret.*—Received in 1895 from M. Crawford, Cuyahoga Falls, O. A perfect flowered variety of vigorous growth. It mats with moderate freedom and has been badly affected by leaf blight. Berries large to very large and yield small.

*Mary.*—A very vigorous imperfect flowered variety. It mats with great freedom but has been badly affected by leaf blight. Berries large to very large, regular, firm and of good flavor. The yields for the last two years have been very disapppointing, as this variety promised so much in 1897 when it produced such an immense crop. That crop has a great deal to do with the size of its average yield in the matted row, as will be seen in the tables.

*Meek's Early.*—An extra early variety. Flowers bisexual, flavor fine and sweet, flesh firm and color dark red. Yield small. It produces good medium sized berries for about a week or ten days or until the early to medium varieties come into full bearing, and for this reason is largely grown by market growers. After the above mentioned period the size rapidly decreases and it is practically worthless. Over one-half the crop for this season was produced during the first eight days, while its entire season extended from June 4th to the 27th inclusive.

*Ohio Centennial.*—Received in 1892 from Geo. Townsend, Gordon, O. This is a medium to late variety of very great vigor, which mats quite freely and is little affected by leaf blight. Flowers perfect, berries very large and yield good, the average for four years in the matted row being 6,034 grams, or at the rate of about 150 bushels per acre. As will be seen in the table the average size of its berries was the largest of any grown here this year.

*Perkins No. 1.*—Received for trial in 1894 from Jackson & Perkins, Newark, N. J. An imperfect flowered variety of vigorous habit, but which is not very free in matting. Leaf blight has affected it considerably. Its season is late, and its berries large to very large and finely flavored. The matted row has given an average yield for the last four years, of 4,086 grams, which is at the rate of about 100 bushels per acre.

*Quality.*—Received from M. Crawford, Cuyahoga Falls, O., in 1896. Bisexual. Berries large, irregular and solid. Yield extremely small, in fact the smallest of any grown here. It will be discarded.

*Riehl's No. 25.*—This variety and the three following it, were received from E. A. Riehl, Alton, Ill., in 1899. Bisexual. Plants produce vigorous runners with great freedom. Blighted considerably. Foliage large, dark green, berries very large in size, conical, red, firm and of good quality. Yield good this year. Season medium to late.

*Riehl's No. 26.*—Flowers bisexual. Berry, large to very large, abruptly conical, dark red and solid. Quality and yield, good. Not quite so vigorous or so free in producing runners as the preceding. Both are promising varieties. Season medium.

*Riehl's No. 27.*—Bisexual. Berry rather small in average size, bluntly conical, bright red, many seeded, flesh firm. Season medium. Yield is not so promising as the preceding.

*Riehl's No. 28.*—Flowers perfect, berry large, bright red, many seeded and solid. Yield and season almost the same as No. 27.

*Sample.*—Received from C. S. Pratt, Reading, Mass., in 1898. Flowers imperfect. Plants vigorous, producing runners with remarkable freedom, and have been little affected so far by leaf blight. Berry large, conical, regular, bright red. It has few seeds and is quite firm. As it was situated upon an extremely dry spot the average yield of 2,289 grams is all the more meritorious. Toward the latter part of the season considerable fruit literally dried upon the plants.

*See No. 2.*—Received from H. S. and A. J. See, Geneva, Pa., in 1894. Pistillate, berry medium to large, plants vigorous and mat with moderate freedom. Yield good. The average yield of the hills is tenth and that of the matted row is eighth in rank.

*See No. 3.*—Received same as preceding in 1895; as were also No. 4 and No. 5. Plants not vigorous, yet strong, but do not produce runners very freely and have been considerably affected by leaf blight. Flowers imperfect. Berry large to very large, and yield fair, averaging about 80 to 100 bushels per acre.

*See No. 4.*—Pistillate. A little stronger than the preceding, possesses a little more freedom in matting and was less affected by leaf blight this year. Average size of berries smaller while the yield was much larger. Berries almost round, large to very large and many seeded.

*See No. 5.*—Pistillate. Berries are large, broadly conical, have few seeds and an acid flavor and are quite firm. This year the plants are more vigorous in growth and matting than either No. 3 or No. 4. Yield good.

*Townsend.*—Received from Geo. Townsend, Gordon, O., in 1892. An imperfect flowered, late variety. Plants vigorous, while runners are produced with very little freedom. Slightly affected by leaf blight. Yield good. Berries large to very large, dark red, broadly conical, regular and firm. Quality good.

*Warfield.*—The largest yielding variety grown here for the last four years and too well known to need any description.

## RASPBERRIES.

The following table gives the name and color of the varieties grown here and also the yields and average size of berries for this season. All weights in grams.

(Explanation: B., black; O., orange; P., purple; R., red; Y., yellow.)

| Name. | Color. | Yield for 12 plants. | Average weight. |
|---|---|---|---|
| Ada, | B | 4,398 | 1.04 |
| All Summer, | R | 8,370 | 1.88 |
| Brackett's No. 101, | B | 4,300 | 1.39 |
| Brandywine, | R | 4,770 | 1.43 |
| Brinkle's Orange, | O | 3,472 | 1.30 |
| Caroline, | Y | 8,280 | 1.48 |
| Columbian, | P | 1,890 | 2.08 |
| Conrath, | B | 15,400 | 1.51 |
| Cuthbert, | R | 6,232 | 1.68 |
| Eaton, | R | .............. | 1.76 |
| Fadely, | B | 3,450 | .87 |
| Golden Queen, | Y | 8,120 | 1.63 |
| Gregg, | B | 4,620 | 1.12 |
| Hansell, | R | 5,591 | 1.61 |
| Herstine, | R | 2,625 | 1.56 |
| Huddle's No. 500, | B | 5,850 | 1.29 |
| Kansas, | R | 7,695 | 1.73 |
| Loganberry, | P | 5,520 | 3.67 |
| Lovetts, | B | 6,630 | 1.04 |
| Mammoth Cluster, | B | 5,143 | 1.14 |
| Marlboro, | R | 3,750 | 1.79 |
| Mills, | B | 13,068 | 1.23 |
| Ohio, | B | 5,700 | .86 |
| Older, | B | 12,577 | 1.29 |
| Onondaga, | B | 16,370 | 1.33 |
| Philadelphia, | R | 4,567 | 1.51 |
| Rancocas, | R | 1;253 | 1.52 |
| Shaffer's Colossal, | P | 13,644 | 1.06 |
| Smith's Prolific, | B | 3,467 | .99 |
| Thompson, | R | 4,718 | 1.43 |
| Turner, | R | 8,532 | 1.73 |
| Wineberry, | O | 6,224 | .75 |

The yields in the above table still show evidences of the effect of the severe winter of 1899. The varieties which proved themselves perfectly hardy that year were Gregg, All Summer, Mills and Onondaga. Those frozen slightly were, Mammoth Cluster, Smith's Prolific, Lovetts and Conrath. Those almost entirely frozen were, Marlboro, Rancocas, Loganberry, Columbian and Wineberry. The remainder were frozen back from one-fourth to three fourths.

### NOTES ON VARIETIES.

*All Summer.*—A very vigorous, red fruited variety. Season late.

*Columbian.*—Too tender for this locality without protection. Otherwise a very fine variety.

*Conrath.*—Received from Birdseye & Son, Hopewell, N. Y., in

1898. A variety of vigorous habit, which has withstood the test of severe weather fairly well and yields very large crops of fine, black berries of fair average size.

*Cuthbert.* —The old standard market, red variety.

*Eaton.*—Received in November, 1898, from Amos Garretson, Pendleton, Ind. This is a red variety. It bore some fruit this season, but not enough to consider. It was pretty severely injured during the winter of '99, having just been planted and it has not yet recovered. The average size of the berries produced was good. A better report might be expected later.

*Golden Queen.*—The best yellow variety grown here. It is not so soft and does not turn to such an unsightly color as do the others when bruised. It is larger in average size but not in yield. It yields good crops, however.

*Loganberry.*—This berry is too tender for this locality without protection. It bore a fair crop this year, owing to the protection given it last winter.

*Lovetts.* —A very early black cap variety. Berries small and yield fair.

*Mammoth Cluster.*—The best very early black cap variety grown here. Berries and yields fair in size.

*Marlboro.* —A fine, large fruited red variety which has not proven itself perfectly hardy here.

*Mills.*—Received from Birdseye & Son, Hopewell, N. Y., and planted in 1898. A good black cap variety. Yield very good, and size, shape, quality and firmness of berries satisfactory. Perfectly hardy.

*Older.*—A fine black variety that was frozen pretty severely but seems to have completely recovered. Although fine crops have been the rule, that for this year is extra fine. The only fault with it is that the berries are a little soft for shipment.

*Onondaga.*—Received in 1898 from Birdseye & Son, Hopewell, N. Y. Another black cap variety which is doing very well indeed. It bore the largest crop of all this year. Season medium to late.

*Shaffer's Colossal.*—A very vigorous growing purple fruited variety. It bore a large crop this year.

*Turner.*—Almost perfectly hardy and bears large crops of good average sized berries.

## BLACKBERRIES.

This year's crop of this fruit was almost a failure. The yields were all very small. However, a few varieties might be mentioned, for as some are well known, the following figures and notes can be used in comparison:

*Erie.*—This is about the best yielding variety grown here as well as the one which produces the largest berries. The yield of six plants this year was but 3,745 grams.

*Ancient Briton.*—This is a new variety here, having been received in 1898 from Birdseye & Son, Hopewell, N. Y. It bore a crop this year of 3,630 grams on six plants. The average size of the berries was 1.47 grams, while that of Erie was 3.10 grams. Growth vigorous and free from rust so far.

*Agawam.*—Also received from Birdseye & Son, and planted in 1898. It is very strong in growth and bore a fair crop for this year of 2,215 grams. The average weight of the berries was 2.34 grams.

*Allen.*—Received from W. B. K. Johnson, Allentown, Pa., and planted in the spring of 1898. A strong yet not vigorous growing variety. It is as early as Early Harvest, which variety it greatly resembles in shape size and flavor of its fruit. The yield for this year was fair, being 2,948 grams for six plants. The average size of the berries was 1.49 grams.

## CURRANTS.

All yields given in the following notes are computed for six plants, since the number in actual cultivation varied considerably in the different varieties.

### NOTES ON VARIETIES.

*Cherry.*—A vigorous growing red fruited variety. Height about four feet. Berries large. Yield this year was 10,960 grams. First picking was made June 15.

*Fay's Prolific.*—The largest red currant grown here. Fruiting season began June 12. Yield, 14,370 grams, growth vigorous, height, three feet.

*Red Dutch.*—Growth strong but not vigorous; height four feet. Yield this year, 16,605 grams. Berries medium in size. First picking was made June 12.

*Red Grape.*—Height four and one-half feet, growth vigorous. First ripe June 12. This variety produced the largest yield of all, it being 27,435 grams. Berries small.

*Storrs & Harrison.*—This variety produced the second largest yield, its weight being 22,500 grams. Plants very vigorous and free from rust; height, four feet. The date of ripening of first fruit was June 14. Berries medium in size.

*Versailles.*—A vigorous growing variety; height three feet; yield 9,160 grams. Berries medium to large. First ripe fruit June 15.

*Victoria.*—June 12 was the date of ripening of the fruit and the weight of the yield was 12,660 grams. Berries medium in size. Plants very vigorous; height four feet.

*White Grape.*—Berry white and large in size. Plants strong in growth and little affected by rust. The yield was 6,980 grams; date of first ripening, June 12.

## GOOSEBERRIES.

*Chautauqua.*—Yield 17,010 grams; growth of plants rather weak; height two and one-half feet. First picking was made July 5. Berries large, oval.

*Crystal.*—Received from Birdseye & Son, Hopewell, N. Y., in 1898. Height two feet and growth vigorous. Berries medium and yield 7,740 grams. First picking July 5.

*Downing.*—This variety bore the largest crop this year, it being 51,885 grams. Height four feet and growth very vigorous. Berries round, and medium sized. Picked July 3.

*Golden Prolific.*—This variety is rather weak in growth, and produces extremely small crops of fine large oval shaped berries, which are of a greenish yellow color when ripe. Height two feet. Yield this year only 255 grams. Picked July 5.

*Houghton.*—Height four feet, growth very vigorous. Berry small, round and red when ripe. Yields very large as a rule, that of 49,038 grams for this year being no exception. The first picking was made July 3.

*Industry.*—A very large fruited variety. Does not do well at all, here. Height one and one-half feet, and growth very weak.

*Pearl.*—Received from A. L. Wood, Rochester, N. Y., in the spring of 1895. A vigorous variety bearing medium sized berries. Yield very good, that for this year being 37,928 grams. Picked July 5. Height three feet.

*Pearl.*—Received from Birdseye & Son, Hopewell, N. Y., in 1898. Height two feet; growth vigorous, berry medium in size. Yield this year, 5,860 grams. Same as preceding.

*Roesch.*—Growth vigorous, height three feet, berries large to very large, oval in shape. Yield 41,160 grams. Picked July 5.

*Smith.*—An early variety. Berries medium in size, growth strong. Height three feet; yield 7,991 grams. Picked June 25.

*Triumph.*—A large fruited variety which yielded 33,915 grams this year. Height three feet and growth is vigorous. Picked July 5.

*Wellington Glory.*—Received from Birdseye & Son, Hopewell, N. Y., in 1898. Growth vigorous, height three feet. Berries large. Has not borne a crop as yet, from which an estimate might be made of its value.

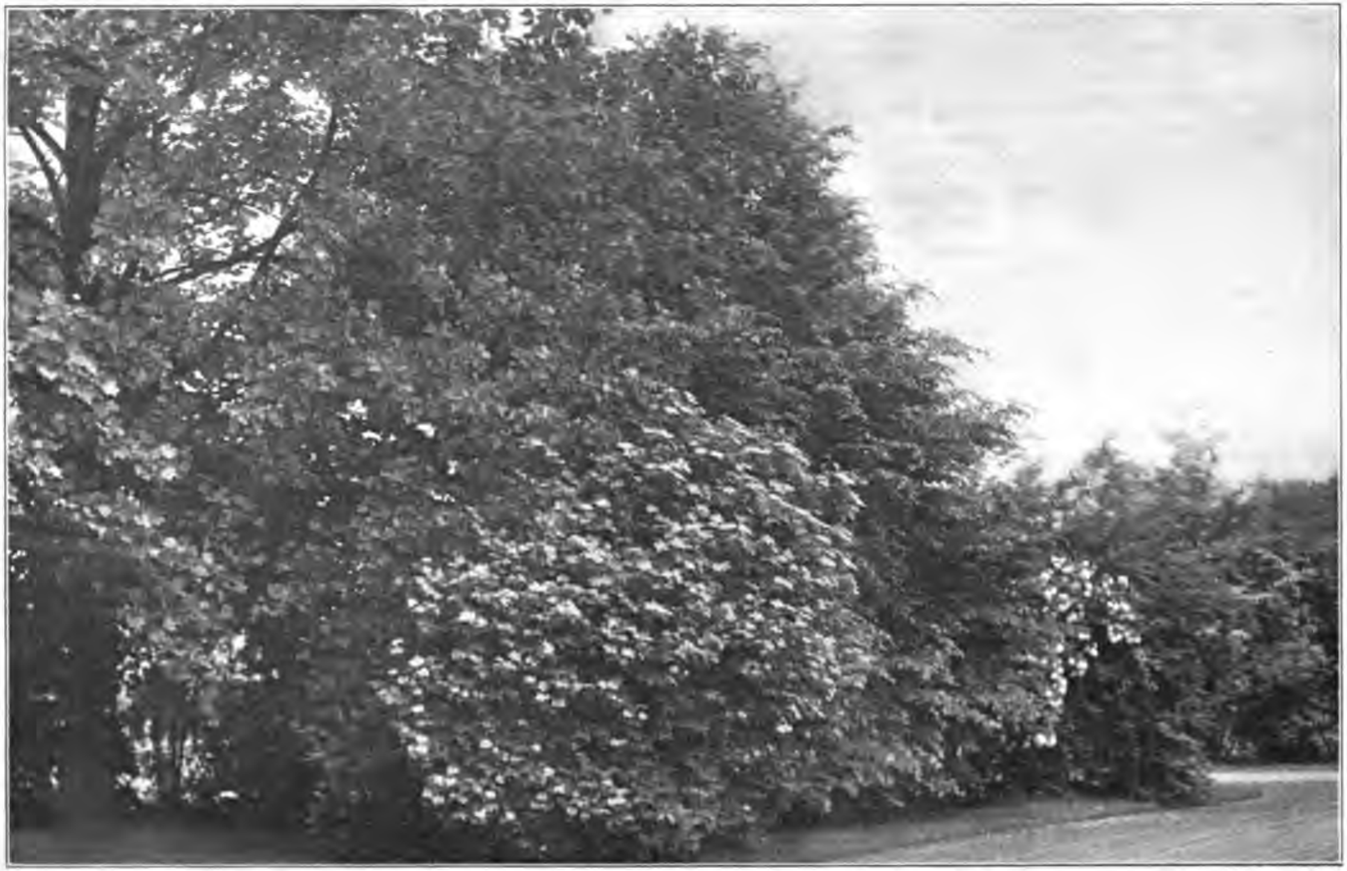
# THE PROPER USE OF SHRUBS.

By George C. Butz,

When a tree is planted about a home, its location is usually chosen with considerable care and consultation; furthermore, there is generally in the mind of the planter a valid reason for the planting of the tree. It may be he wants a line of street trees to shade the sidewalk. The idea is a good one, and the proper position for the trees is practically fixed by the location of the sidewalk. Again, a driveway leading to the house is to be flanked with trees on either side. This is also a proper use of trees and locating them is but little more difficult than in the first case. Another instance is in planting a tree by the house with no other purpose than to provide shade upon the lawn. Sometimes it is located in front of the house and sometimes at a side or even to the rear. No further thought of the appropriateness of the kind of tree or the effect upon the landscape is entertained and yet few serious mistakes are likely to be made by such simple planting. Their branches are raised so far above the plane of vision that they seldom stand as obstructions to a view. Likewise, the planting of vines about our homes may be done with little fear of results, for by their very nature we are led to place them near a wall, a trellis, a tree, or a fence. We would not think of planting them promiscuously over the lawn to take their own course. We see, therefore, that trees and vines may commonly be planted without incurring after criticism as to their location. The problem with respect to shrubs, however, is very different.

The chief ornamental value of shrubs depends upon the mass or aggregation, arranged with due respect to the relative proportion of the species employed and the harmony and contrast of their colors and leaf-forms. The specimen shrub is the nurseryman's delight, but the landscape gardener seeks to destroy its symmetry by close planting in running borders or massed shrubbery. Effectual planting of shrubs is difficult because we choose commonly a single plant of a kind, then assign it space for its perfect development. When that is attained we have the specimens of the nursery exhibit, of which the like cannot be found in nature.. Our visions of Rhododendrons in our mountains over which thousands have exclaimed in ad-ation are not the rounded forms with grassy walks between

EFFECTIVE MASS OF RHODODENDRON.
Photo. by J. HORACE MCFARLAND.



RUNNING BORDER.—Viburnums backed by Beech and Tulip Trees.

Photo. by J. HORACE McFARLAND.

as seen on many lawns, but great masses of plants interlocking their branches high and low, each presenting to light and view its bouquet of lovely blossoms, making a mass of glossy foliage and pink-white flowers through which pierce tall trees with overhanging branches. The individual plant is not discerned and it never receives criticism. The beautiful Meadow-sweet that has frequently enticed us over marshy lands through tangles of shrubs does not have the freedom so commonly given it in our gardens, yet we prefer to have its memory perpetuated in the picture of the swamp and not as in the strange picture of the nurseryman's catalogue. The safest guide for the successful planting of shrubs is nature's plan of massing, grouping and associating the available material subject to the limitations and character of the grounds planted. Before undertaking such work we may be greatly helped by walking through a bit of nature's garden until we meet a piece of shrubbery that is particularly pleasing to our sense of beauty, then studying the facts presented with a view to their reproduction upon our grounds to imitate the picture, just as the painter will study the elements, the proportions, the color and the background to reproduce the picture upon his canvas. Such a study cannot fail to blot from our minds those false notions of plant-beauty that have for their standards of plant forms the perfect blockheads, as cubes, globes, balloons, cones, pyramids, etc. Prof. L. H. Bailey, in his excellent bulletin on the planting of shrubbery (Bul. No. 121, Cornell, 1896), has well said "One's place grows to be a reflection of himself." Then surely we will strive to exclude all blockheaded shrubs and trees from our grounds. The word "picturesque" has recently been made use of very freely to describe that pleasing natural form of a tree or shrub, or its unique setting, and has acquired a distinct meaning with the aesthetic. It could not be applied to a group of shrubs, in which each plant stands apart from its neighbor, trained and pruned into the most perfect symmetry and regular form. But if, on the other hand, we saw a shrub of most irregular outline, yet having withal an equal bulk of material to the right and left of a perpendicular, and so associated with the grass below and the objects surrounding it, that harmony prevails, then we may truly say it is picturesque.

Running borders of shrubs, which are appropriately placed to the right and left of a lawn, may be made prolific of picturesque groups by the proper assortment and association of kinds. For when one shrub is in the glory of its beauty its neighbors lend it brilliancy by their own subdued colors, as a bride adorned for the wedding carries the honors of the bridal party. Thus the Forsythia, flanked with Weigelias and Spiraeas, and backed with a Birch or other small tree, has the beauty of its thousand golden blossoms bursting forth in April sunshine, greatly intensified by the proximity of the wintry twigs and unburst buds of the associated plants. Then in May, we almost forget the attraction of the Forsythia while looking in the many white faces of the Spiraea clusters, made whiter by contrast with the pure green Forsythia foliage. And again, in June, when the Weigelias seem to blush at their own prominence, we exclaim, there is no prettier shrub in all the world!

The entire border may thus be made a panorama of changing beauty, displayed all the year round. When the flowers have all disappeared the changing tints of the autumn leaves play their part and then give way to the ripened fruits and colored twigs that have been judiciously included in the list of shrubs.

Such a border of shrubs may be properly and effectively used as a screen cutting off the view of the kitchen garden or any other unattractive view, from the lawn. In the larger ground, one-half acre and more in extent, it is often desirable to secure seclusion and privacy upon the lawn. This may be effected by running such a border along the street line. Here it will also serve to stay much of the dust that would blow from the street to the house in rural districts.

These borders may include a great variety of shrubs. The width should vary much, making a "crooked" and not a straight line against the lawn. The border may be slightly broken at intervals for a line of visions, if desirable. In fact, the best border planting appears to the average mind at first sight as having been done without order or design. There are no "rows," the spaces are all at random, and the kinds are intermixed without apparent reason. And yet, the most extreme care is taken to allot each plant such a place and space that when it has grown to its average dimensions it is not concealed or crowded by its more vigorous neighbors.

Summer pruning in this shrubbery is necessary to keep the aggressive species from crowding out the weaker though perhaps prettier neighbors, and to prevent any plant from assuming eventually an undue portion of the border. Summer pruning is recommended above winter or spring pruning for two reasons: First, the cutting of ambitious shoots or of weak unprofitable wood can then be done without exposing the work of the knife, and second, as most shrubs produce their flowers upon wood made the previous season, summer pruning gives that wood the opportunity of first yielding its flowers. So commonly when spring comes and lawns are "cleaned up and trimmed up," the shrubs get such a trimming that all that is graceful and picturesque about them is cut away, and all the stiff black stalks laid bare remain bare throughout the summer season. The writer has frequently witnessed such injudicious pruning.

e case a magnificent Forsythia suspensa occupying a space

GROUP OF SHRUBS BACKED BY SILVER MAPLE.
Photo. by J. HORACE MCFARLAND.

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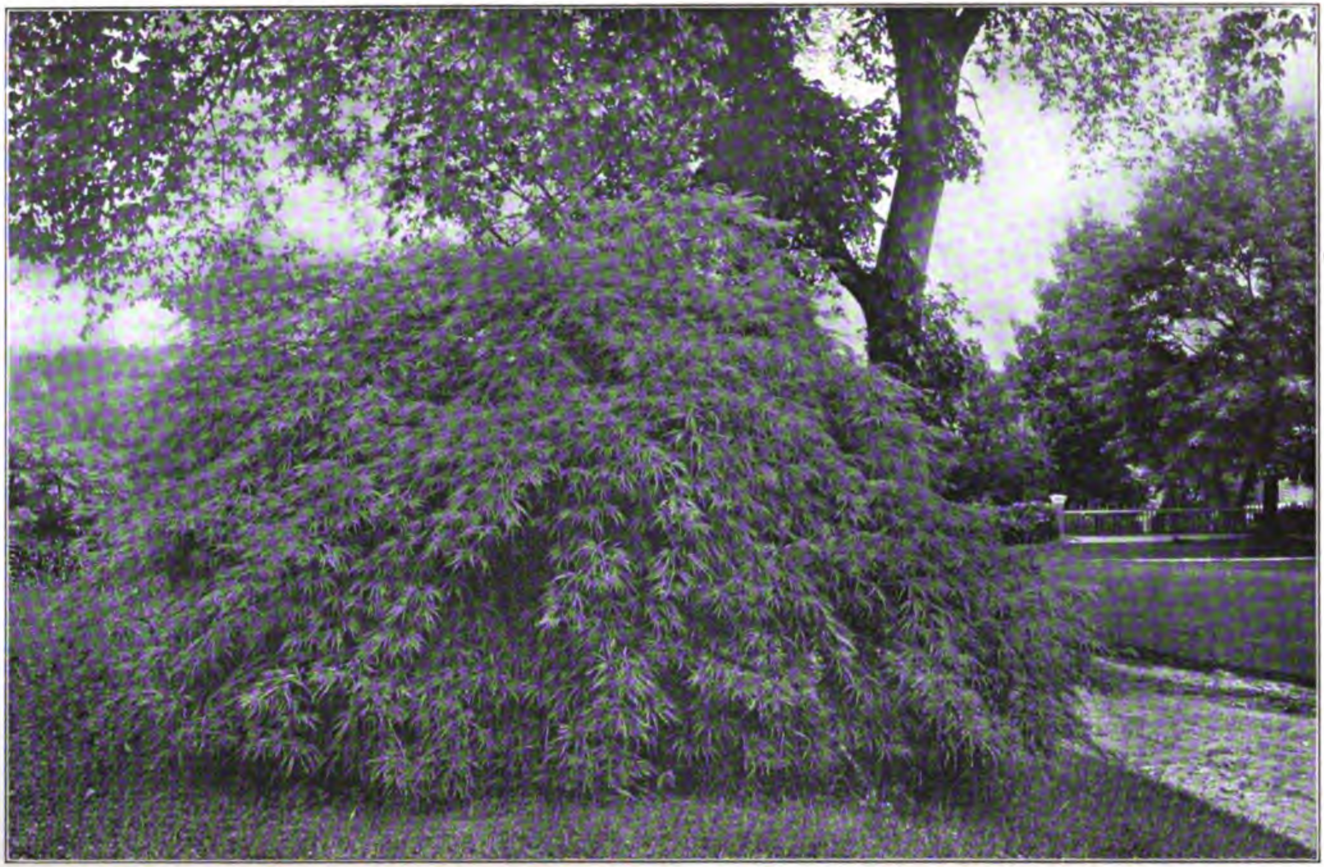


Japanese Maple.—Single Specimen.
Photo. by J. Horace McFarland.

eight feet in diameter was totally beheaded because its form was not a perfect sphere, and this was done in April just one week before the shrub would have been a cloud of golden blossoms. It is needless to say that for two years after scarcely any flowers were produced on this plant.

## GROUPING OF SHRUBS.

There is often some portion of the homeplot that is best covered with a group of shrubs. A group differs from a border in that it must present a good face on all sides. A group calls for a more careful selection of shrubs. From a small group where only six or eight plants can be used, the tall and upright shrubs should be generally omitted. Such as have an underground spreading habit should be avoided. A group is always more beautiful if it can be associated with a bit of rockery, a small rustic house, or even if it has a rustic seat by it. At the angle of diverging walks a group of shrubs may be made picturesque. In this instance the border lines of the walks furnish the bit of formality to the picture and stand as the reason for the group in that location. The most common occasion for a small cluster of shrubs is at an angle of the house, where a very beautiful picture can easily be wrought out by involving the masonry, front steps, or other portions of the architecture of the house.

## HEDGES OF SHRUBS.

A hedge is an unnatural feature of adornment. There is seldom a real occasion for one, particularly upon small grounds. In large areas it may be introduced as an element of formality to intensify the rarer beauty of the natural grouping about it. It is not an uncommon sight to see a hedge of shrubs or low evergreens upon village lots without any other planting. The Privets, Spiraeas and Japanese Quince when used for ornamental hedges, possess a beauty that makes them tolerable when it is necessary to have the hedge.

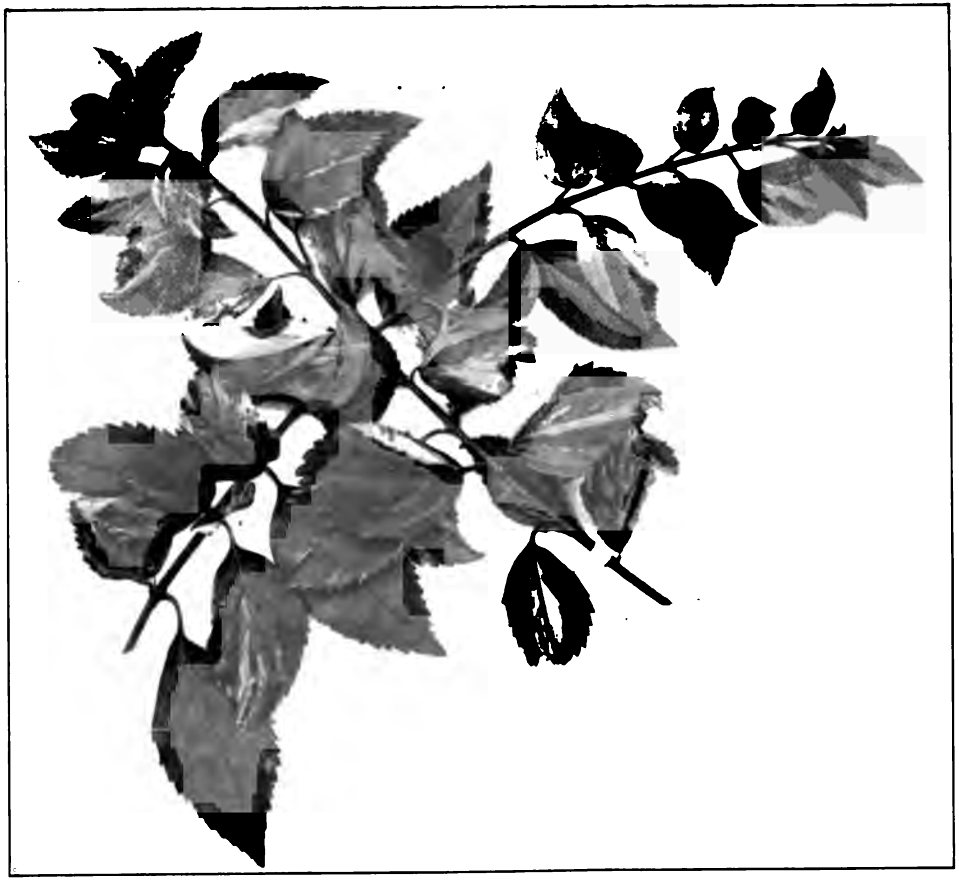
## SHRUBS PLANTED SINGLY.

Specimen plants standing singly have a charm that must not be overlooked on even the smallest grounds. The small or dwarf trees are most effectively employed in this manner and should be considered among shrubs rather than with trees strictly. Most beautiful among such small trees are the Flowering Apple (Malus Malus floribunda), Flowering Dogwood (Cornus Florida) and its variety rubra with pink blossoms (bracts). The American Judas Tree (Cercis Canadensis) and the Japanese Maples. The last named are just now very popular favorites. They deserve to be more generally planted, especially the thrifty and hardy varieties. The beautiful illustration of a well grown Japanese Maple shows many of its merits for the lawn, but cannot display the color effects of these rare trees.

It is not to be denied that many kinds of shrubs when planted alone in good congenial soil possess such a grace of habit or beauty of foliage and flower that their standing apart from the masses and groups is justifiable. Strong plants of the Hydrangea paniculata, Spiraea Van Houttii, or the shrub-like Japanese maples are properly used in this way. Many varieties of shrubs, as of other plants, too, are originating under the care of horticulturists. These varieties possess a merit often that would not be appreciated if planted in the border; hence, must be planted where their special characteristics can be seen. Such plants are the varieties with variegated foliage, laciniate leaves, weeping habits, etc.

*Forsythia suspensa var. variegata.*—Of all the Forsythias none is more beautiful and graceful than F. suspensa, and after the early flowering period is past its rich crop of dark green leaves makes it attractive throughout the long summer. Upon one of these shrubs on the College campus in 1896 appeared a branch with leaves distinctly variegated with a pure white. So distinct was it that it was attractive a hundred feet away. The writer sought to perpetuate this "sport" realizing how great an acquisition a good variegated Forsythia would be. A cutting was made of six inches of the growth leaving four buds in the axils of variegated leaves yet upon the shrub. These buds subsequently produced shoots with only a very slight amount of variegation in the leaves, except one from which the sprout was totally white and consequently too weak to be of any value. The cutting taken in 1896 rooted freely and is now a magnificent plant growing with the vigor of the parent species. The variegation remains strong. The white is irregularly distributed through the green. Some leaves being mottled with small angular sections of white and green, others are marked with streaks of white. Sometimes an entire half of a leaf is white, the other half being wholly green. Frequently there are patches of a light green which add to the beauty. In the very young foliage the variegation is a cream-white color, making the tips of the new growth prominent. The plant, but four years old from the cutting, is strong enough to indicate that it will flower with the same freedom that is possessed by the green parent.

*Sambucus pubens var. dissecta*, Britton.—Attention is called to this novelty among shrubs, because it has not yet reached the nurseryman. The specimen upon our grounds was contributed by the venerable horticulturist Wm. G. Waring, of Tyrone, Pa., who originally found the variety in the mountains of Centre county, Pa., about 1861, while he was connected with the Pennsylvania State College, then known as the Farmers' High School. I have assumed



Forsythia Suspensa Var. Variegata.
Originated 1896 on Campus of the Pennsylvania State College.

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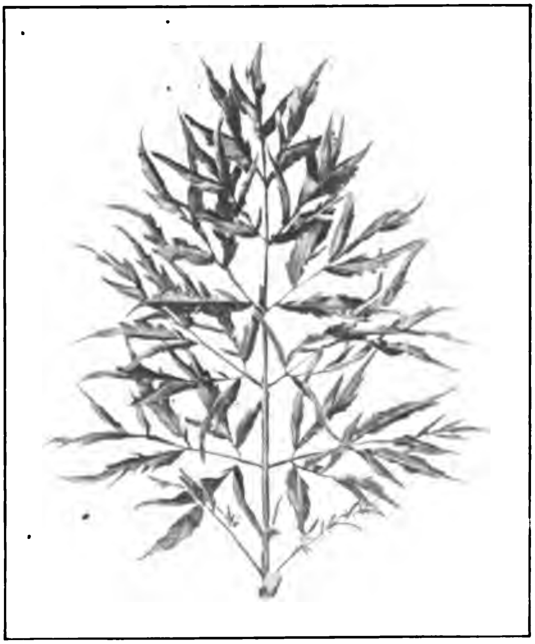

SAMBUCUS PUBENS VAR. DISSECTA.

that this is the same as the variety referred to by Britton in Britton and Brown's Illustrated Flora under the above name and described in Mem. Torr. Club, 1894. It is reported as growing near Lake Superior and in Pennsylvania. However, a remarkable feature of the plant on our grounds is the purple color of the foliage in the spring. It is as pronounced as the purple coloring in Berberis vulgaris var. atropurpurea, but fades out towards the end of the season when the foliage ripens. The laciniate leaves are, as shown in the illustration, very much cut, each leaflet of the species being pinnate pinnatified. By a severe pruning in March, the new growth becomes very strong, and each compound leaf becomes twelve inches long by eight inches wide, and the height of the shrub may be from six to ten feet. This variety is not inclined to set fruit as freely as the species, hence the beauty of the red berries of S. pubens cannot be considered as belonging to the variety..

## ORNAMENTAL SHRUBS OF RECENT INTRODUCTION.

The following shrubs are a part of a collection sent by Dr. D. G. Fairchild, special agent in charge of foreign introductions conducted by the United States Department of Agriculture. The plants and cuttings were received in March and April, 1898, and planted where they could be cared for and their development could be observed. Among the list were several ornamental trees and bush fruits from foreign countries, but they are not referred to in this report. The majority of the plants are from Siberia and Upper China, therefore the question of hardiness is not a doubtful one. The adaptability of a plant to a new region cannot be determined by the study of temperature and rainfall alone, the problem is complicated by the many conditions prevailing in a region that are conveniently summed up in the word "climate." The actual trial of a new plant is the only sure method of determining its adaptability in a strange country, and often no other explanation for success or failure can be given than that the "climate" proves congenial or the reverse.

Among the shrubs referred to below, there is nothing possessing such extraordinary merit that it should supplant the well known favorites of our lawns and parks; but with the increased interest in ornamental planting the nurserymen and landscape gardeners will find many of them valuable on extensive grounds to secure that variety of display which is always pleasing to the eye of the aesthetic and the taste of the cosmopolitan. Our people are fast becoming citizens of the world, fraternizing with other peoples, rejoicing in the scenery of other countries and subsisting upon products from the four quarters of the globe. A liberal use of foreign plants may be made without excluding from our lawn and parks the multitude of indigenous plants of rare ornamental value and well known adaptability.

The past two years have been the most trying period in a half century upon plants in the nursery and upon the lawn, over nearly the entire country. In February, 1899, this particular region suffered a cold of —20° F. through a period of a week or ten days and many plants regarded as hardy here were either severely injured or killed outright. Notable among them were the following: Forsythias, Berberis Aquifolium, many roses, Rhododendrons, Laburnum vulgare and Magnolia purpurea, all severely injured. Cupressus Lawsoniana, a thrifty tree ten feet high, was killed to the ground. The following winter, though less cold, caused the death of several plants that had been injured and failed to regain their former vigor. Furthermore, the summer of 1900 has been severe upon plants because of the excessive heat and long continued drouth. It may be said, therefore, that the following shrubs have lived and flourished through the severest climatic conditions that they are likely to encounter in this State.

*Amygdalus nana.*—A dwarf spring flowering shrub related to the Dwarf Flowering Almond (Prunus Japonica flore pleno, erroneously called Amygdalus pumila). The plant attains a height of two to three feet; the flowers are rose-colored, appearing in profusion in April, the foliage is small serrated and glabrous. This plant is a native of Tartary and has survived on our grounds the severest climatic conditions that it is likely to encounter in Pennsylvania at any time both in regard to extreme cold and long summer drouth with high temperature. Our plant of this species is now one foot high with many branches and gives promise of a successful introduction.

*Artemisia Abrotanum.*—The Artemisias are aromatic herbs or small shrubs, usually grown in country places for their medicinal properties. Some of them are commonly known as Wormwood, Mugwort, Southernwood and Old Woman. The species here referred to is the Southernwood or Old Man, which is an old inhabitant of English Gardens and not new in America. It is a native of Europe, grows three to five feet high in good soil. Its finely divided leaves, together with the pleasant fragrance about it, make it a very desirable plant for decorative purposes upon the lawn. The flowers are in small heads (compositae) arranged in loose panicles, but are neither conspicuous nor beautiful. They are yellow in color and dry upon the plant making their appearance from August to October. The plants in our shrubbery are now mature shrubs three and one-half feet high, making a hemispherical form of finely divided leaves. This plant can be easily propagated by cuttings, and will thrive in almost any location.

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*Artemisia procera.*—This species closely resembles the preceding in general aspect, although the branches are more erect and longer making a shrub six to eight feet high when full grown. The fragrance of the foliage is more pleasant. This is a native of southern Europe.

*Berberis heteropoda.*—Several species of Barberry have been in cultivation so long that they have a distinct use in lawn and park planting. The holly-like and evergreen foliage of some and the bright-colored berries of others make them attractive in both winter and summer. The species now introduced is most like the common Barberry (B. vulgaris) or our native one (B. Canadensis). It attains a height of four to six feet with spreading branches. The leaves are broadly ovate, pale green, one to two inches long. The orange-yellow flowers produced in racemes in May are fragrant and the fruit which follows is dark blue. Our plants of this are strong and will evidently adapt themselves to this country as well as the better known species. B. heteropoda is a native of Turkestan.

*Berberis Thunbergii.*—A valuable shrub making a dense low growth, its form being an oblate sphere resting gracefully upon the ground. The branches appear fan-shape, extend themselves horizontally supported by the graceful curves of the older wood. The leaves are small, obovate or spatulate, smooth and entire, clustered in threes or fours in the axile of the alternate spines. The leaves become crimson and scarlet in the fall beginning in August. and when the foliage has dropped in October the bright red fruits are very showy throughout the winter, hanging in straight rows under the horizontal branches. The plants received from the Department of Agriculture were too frail on arrival to live, however several very fine specimens of this neat little Japanese shrub are growing upon the College campus.

*Caragana frutescens, var. grandiflora.*—The shrubby Caraganas are handsome ornaments when in flower; the yellow pea-shaped blossoms appear in profusion among the short-petioled leaves. The latter being compound of four leaflets give the shrub a very leafy appearance. This species is the one most commonly planted being perfectly hardy and easily handled. It is a native of Southern Russia to China. The variety grandiflora resembles the species but is superior in having larger flowers. The shrub grows from five to ten feet high and when in flower it reminds one of the sweet-scented conservatory plant Cytisus racemosus (known to florists as Genista).

*Caragana pygmaea.*—This is a diminutive species of Caragana coming from Siberia. It is perfectly hardy but has not displayed much freedom of growth in our experience with it. The foliage is small, the four leaflets being linear lanceolate. The shrub at best does not exceed three feet in height and the branches are too slender to stand erect. According to Rehder, this species "grafted high on C. arborescens forms a graceful standard tree with pendulous branches." Cyc. of Amer. Hort.

*Cornus Sibirica* (Probably C. alba var. Sibirica). The plant of this shrub was very frail when received and never grew. It is well known, however, that the Dogwoods are not difficult to grow. This is one of the forms so attractive in winter because of the bright red branches and coming from Siberia we may feel certain it will prove hardy in Pennsylvania.

*Crataegus sanguinea.*—We have many native Hawthorns that are valuable ornamentals and it is not likely that any novelty will supplant one of the well tried European or American species. However, we can cheerfully welcome other species to the brief list of shrubs that attain the height and form of small trees. They are so much needed to stand as prominents in the large border of shrubbery, and in limited grounds where the larger trees would not be admissable. Hawthorns appeal to our sense of beauty on four different occasions during the year; first, through April, May and June with their profusion of apple-like blossoms; second, throughout the summer with shapely or picturesque heads of glossy green foliage; third, during September and October the autumnal tints are as varied and as handsome as of any other tree, and lastly the ripened fruits in shades of red or purple hang in many clusters long after the foliage has dropped. C. sanguinea is another introduction from Siberia. It is noted for its large flowers with purple stamens and its large blood-red fruits. The trees on our grounds are making strong upright shoots three to five feet in a season.

*Diervilla Middendorffiana.*—Another Siberian plant for which there is an opening. Diervillas (more commonly known as Weigelias), have in their flowers the colors of white, red and purple, but no yellow. This new species affords a shade of yellow that is not strong but can be improved under cultivation. The plant sent us by the Division of Forestry, being a weak one, never grew.

*Deutzia parviflora.*—In general aspect this Deutzia most closely resembles the D. gracilis with larger proportions. It attains a height of five feet, has coarser foliage, and moreover is a much more hardy species than D. gracilis. The flowers, though small, are borne in corymbs of many blossoms appearing in the month of June. Our plant is now two feet high and in a very vigorous condition. The species is found in Northern China and Mongolia.

*Hippophae rhamnoides.*—Sea Buckthorn. This is related to the Eleagnus and Shepherdia. Only a cutting of this was sent and it failed to grow.

*Lonicera spinosa* (L. Alberti) Honeysuckle.—This species is but little known in this country. It is a small shrub not exceeding two feet in height. It resembles a shrubby Hypericum, having small linear or linear-lanceolate leaves, opposite and bluish-green. The branches are erect and rigid, becoming spiny in half alpine regions. The flowers are pink and fragrant. Our plant appears very hardy and in two years has become a strong bushy shrub. It will be found useful in limited borders.

*Lonicera caerulea var. dependens.*—The Blueberried Honeysuckle. This is a larger and coarser plant than the preceding. The leaves are one to two inches long, ovate, glaucous-green. The plant is early at its full height of three feet, loosely branched and scattering. The flowers are not very showy, being somewhat concealed among the foliage because of the short peduncles. Wherein this variety differs from the species L. caerulea is not yet apparent. There can be no question as to its adaptability to our climate.

*Menispernum Dahuricum.*—Moonseed. A vine, resembling closely our native common Moonseed (M. canadense). It is a twining, woody vine; the pretty leaves are broadly cordate, peltate, and a deeper green than our native one. Neither vine is a free bloomer until strong plants are developed. Nevertheless, the beauty of these vines lies wholly in their foliage and twining habit. Our plant of this Asiatic species in three years has not exceeded four feet in growth in a season, whereas the native one in the same time makes a growth of six to eight feet.

*Rosa rugosa.*—Considerable interest has been aroused in this Japanese rose, and its white variety. Its introduction is no longer a matter for experiment. It must be used and regarded entirely as a shrub whose beauty lies in the general effect of its form, foliage and flowers. It makes stout branches four feet high, thickly beset with prickles, though almost wholly concealed by a dense crop of fine foliage, much wrinkled by depressed veins, and being usually of a good green color, it occasions many remarks of admiration. The flowers are very showy, four inches in diameter, with a good red color, appearing freely in June. They are followed by very large fruits which when ripe are orange-red, reminding one of small tomatoes.

*Rosa rugosa, var. alba.*—In all respects this variety is like the species, barring the color of the flowers, which in this case are pure white. This white variety is inclined to be more dwarf than the red one. Rose growers have promptly obtained many valuable hybrids by crossing this with the Teas and other types of roses. Blanc Double de Coubert is a thrifty double white variety of the rugosa rose, with a delightful fragrance. There are about 25 petals in the double blossom and from four to eight flowers are borne in a cluster.

On large plants on our campus this hybrid variety continues flowering all summer and into October.

*Spiraea amurensis*—The Spiraeas are well known as ornamental shrubs and some of them as herbaceous perennials. They are all easy growing and suited to a great variety of uses. This species has already attained a height of four feet on our grounds and flowered freely during the past summer. The flowers are white borne in clusters on the wood of the previous season's growth. The leaves are tri-lobed with the margin doubly serrated. While this species is properly considered an ornamental shrub it cannot rank with the beautiful species and varieties of our nurseries like S. Reevesiana. R. Van Houttei, or S. Callosa.

*Spiraea laevigata.*—The smooth-leaved Spiraea. This Siberian species has a distinct character because of the foliage which is of a different type from any of the many commonly grown types in this genus. The leaves are oblong-lanceolate, entire, four to five inches long, glaucous green, smooth and erect on stiff upright branches. The flowers are white tinged with red and appear in June. This species is dioecious; the male inflorescence is larger and looser than the female. Lovers of Spiraeas will be pleased to welcome this new type. In growth it does not exceed two or three feet in height.

*Spiraea longigamis.*—This species resembles the Plum-leaved Spiraea (S. prunifolia) in type of foliage and habit of plant, and seems to be well adapted to our climate. The plants are over three feet high, but have not flowered yet.

*Syringa Emodi.*—Lilac. The many recent additions to our list of lilacs include several new types with strong characters. It may be a tree-like habit, bolder foliage, or larger panicles of flowers. This species from the Himalayas was introduced into England as early as 1840. It has the habit of a small tree six feet in height, with large leaves, four to five inches long and two to three inches broad. The midrib and the principal veins of the leaf are strongly depressed giving distinction to the foliage. Our specimen is now three and one-half feet high, and has made strong, healthy wood. The inflorescence is a large loose panicle terminating the early growth of the season. The color of the flowers is white or purplish. This species is valuable for single specimens or as prominents in a running border.

## EXCHANGES.

Agricultural Epitomist, Indianapolis, Ind.
American Agriculturist, New York.
American Fertilizer, Philadelphia.
American Fruit and Vegetable Journal, Chicago, Ills.
American Grange Bulletin, Cincinnati, Ohio.
American Horse Breeder, Boston, Mass.
American Sheep Breeder and Wool Grower, Chicago, Ills.
Blooded Stock, Oxford, Pa.
Breeders' Gazette, Chicago, Ills.
Beet Sugar Gazette, Chicago, Ills.
California Cultivator and Poultry Keeper, Los Angeles, Cal.
Chicago Produce, Chicago, Ills.
Connecticut Farmer, Hartford, Conn.
Creamery Gazette, Des Moines, Ia.
Dairy World, Chicago, Ills.
Drainage Journal, Indianapolis, Ind.
Edwards Fruit Grower and Farmer, Missoula, Montana.
Elgin Dairy Report, Elgin, Ills.
Farm, Furnace and Factory, Roanoke, Va.
Farmers' Institute Bulletin, Fayetteville, N. Y.
Farm Home, Springfield, Ills.
Farm Journal, Philadelphia.
Farm and Fireside, Springfield, Ohio.
Farmers' Advocate, London, Canada.
Farmers' Friend, Mechanicsburg, Pa.
Farmers' Guide, Huntingdon, Ind.
Farmers' Home, Dayton, Ohio.
Farmers' Review, Chicago, Ills.
Farming, Toronto, Canada.
Farmers' Tribune, Des Moines, Ia.
Farm Magazine, Milwaukee, Wis.
Hoard's Dairyman, Fort Atkinson, Wis.
Holstein-Friesian Register, Brattleboro, Vt.
Homestead, Des Moines, Ia.
Hospodar, Omaha, Neb.
Home, Field and Forum, Oklahoma.
Indiana Farmer, Indianapolis, Ind.

Irrigation Age, Chicago, Ills.
Industrialist, Manhattan, Kan.
Jersey Bulletin, Indianapolis, Ind.
La Laiterie, Paris, France.
Live Stock Indicator, Kansas City, Mo.
Louisiana Planter, New Orleans, La.
Mark Lane Express, London, Eng.
Mirror and Farmer, Manchester, N. H.
Monthly Florida Bulletin, Tallahassee, Fla.
National Farmer and Stock Grower, St. Louis, Mo.
National Fruit Grower, St. Joseph, Mich.
National Rural and Family Magazine, Chicago, Ills.
National Stockman and Farmer, Pittsburgh, Pa.
New England Farmer, Boston, Mass.
New England Homestead, Springfield, Mass.
New York Farmer, Port Jervis, N. J.
New York Produce Review and American Creameryman, New York.
New Zealand Dairyman, Wellington, N. Z.
Oregon Agriculturist, Portland, Oregon.
Orange Judd Farmer, Chicago, Ills.
Our Grange Homes, Boston, Mass.
Pennsylvania Farmer, Meadville, Pa.
Poultry Monthly, Albany, N. Y.
Practical Dairyman, Indianapolis, Ind.
Practical Farmer, Philadelphia.
Rural Farmer, Philadelphia.
Rural New Yorker, New York.
Rural World, London, W. C.
Southern Planter, Richmond, Va.
Strawberry Specialist, Kittrell, N. C.
Sugar, London, Eng.
Sugar Beet, Philadelphia.
Swine Breeders' Journal, Indianapolis, Ind.
Sanitary Inspector, Augusta, Maine.
Successful Farmer, Sioux Falls, Dakota.
The Golden Egg, St. Louis, Mo.
The Southwest, Springfield, Mo.
Turf, Field and Farm, New York.
Up-to-Date, Indianapolis, Ind.
Veterinary Record, London, Eng.
West Va. Farm Review, Charleston, W. Va.
Western Creamery, San Francisco, Cal.
Western Fruit Grower, St. Joseph, Mo.
Weekly Sun, Baltimore, Md.

Bedford Enquirer, Bedford, Pa.
Central News, Perkasie, Pa.
Clarion Democrat, Clarion, Pa.
Delaware County Democrat, Chester, Pa.
Detroit Free Press, Detroit, Michigan.
Erie Weekly Herald, Erie, Pa.
Johnstown Weekly Democrat, Johnstown, Pa.
Juniata Herald, Mifflintown, Pa.
Leechburg Advance, Leechburg, Pa.
Monitor, Clearfield, Pa.
New York Weekly Witness, New York.
Public Ledger, Philadelphia.
Quakertown Free Press, Quakertown, Pa.
Reading Adler (German), Reading, Pa.
Reading Weekly News, Reading, Pa.
Review, Norristown, Pa.
Sharpsville Advertiser, Sharpsville, Pa.
Village Record, West Chester, Pa.

## LIST OF STATION PUBLICATIONS AVAILABLE.

Reports for 1892, 1896, 1897, 1898-99.

Bulletin 20. Tests of Dairy Apparatus.
Bulletin 29. Tuberculosis in Cattle.
Bulletin 31. Report of the Director for 1894.
Bulletin 37. The Peach Industry in Pennsylvania.
Bulletin 38. A Test of Hand Separators.
Bulletin 40. The Sugar Beet in Pennsylvania.
Bulletin 43. Apples in Pennsylvania.
Bulletin 44. Commercial Butter Cultures.
Bulletin 45. Heated Milk for Butter Making.
Bulletin 46. Variety Tests of Wheat.
Bulletin 47. Sugar Beet Tests in Pennsylvania.
Bulletin 48. Winter vs. Spring Bran.
Bulletin 49. Field Fertilizer Experiments on Tobacco.
Bulletin 50. Distillery Waste; Miscellaneous Cattle Food Analyses.
Bulletin 51. Small Fruits in 1899.
Bulletin 52. Rye Meal and Quaker Oats Feed for Milk Production.
Bulletin 53. Methods of Steer Feeding.

## DISTRIBUTION OF SEEDS OF VARIETIES OF FARM CROPS.

Many inquiries having been received from persons living in various parts of the State, who desire to test or purchase seeds of some of the varieties grown here, we take this means of stating that the Station does not make any free distribution of seeds. We give in our reports the source from which we obtain seeds, and farmers can usually obtain the same by addressing the parties named. We endeavor to grow each variety true to name and use seed from reliable persons or dealers. The small surplus of each variety remaining after securing our seed for the following season is kept, and we will supply parties desiring the same, as long as our supply lasts, charging a moderate price, which hardly covers the expense of keeping seed pure and preparing it for shipment.

# METEOROLOGY.

BY WILLIAM FREAR AND C. W. NORRIS,

It is universally known that the climatic relations of any locality or season determine chiefly the success of the crops raised; but very little is known concerning the exact relation of climatic differences between several locations or seasons to the success or failure of any crop, except in the most general way. It is very desirable, therefore, to fix accurately the climatic conditions under which field investigations are carried on, and to determine, if possible, to what extent and in what way a given change in any of the conditions that go to make up the weather affects the various plants submitted to test.

The work of the past year has been chiefly a continuation of the work of the preceding years, including observations of the kind usually made by the United States Weather Service upon atmospheric phenomena and upon the amount of sunshine.

The results of the observations upon atmospheric phenomena and the amount of sunshine have been reported regularly to the United States Weather Bureau.

## ATMOSPHERIC METEOROLOGY.

The latitude of the Station is about 40 degrees 55 minutes N., and the longitude about 77 degrees 51 minutes W. The altitude of the mercury level of the barometer is about 1,217 feet above sea level. The thermometer shelter is sixty feet northwest of the Station office and stands sixteen feet above the ground.

The apparatus used consists of a standard mercurial barometer reading to 0.001 inch; dry and wet bulb and maximum and minimum thermometers by Green; standard 8-inch rain gauge, standing two feet above the ground level; weather vane and anemometer.

*Meteorological Summary for 1899. Monthly Means, Etc. (Figures within parenthesis ( ) indicate the day of the month.)*

| | January. | | February. | | March. | | April. | | May. | | June. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atmospheric Pressure.** | | | | | | | | | | | | |
| Monthly mean, | ............ | 30.160 | ............ | 30.062 | ............ | 29.946 | ............ | 30.045 | ............ | 30.015 | ............ | 30.020 |
| Highest, | (2) | 30.816 | (11) | 30.629 | (14) | 30.368 | (6) | 30.294 | (24) | 30.252 | (17) | 30.171 |
| Lowest, | (24) | 29.611 | (22) | 29.608 | (19) | 29.356 | (8) | 29.673 | (8) | 29.745 | (20) | 29.794 |
| Monthly range, | ............ | 1.205 | ............ | 1.021 | ............ | 1.012 | ............ | .621 | ............ | .507 | ............ | .377 |
| **Temperature (Deg. Fahr.)** | | | | | | | | | | | | |
| Monthly mean, | ............ | 25.3 | ............ | 21.2 | ............ | 34.3 | ............ | 50.9 | ............ | 60.7 | ............ | 69.2 |
| Maximum, | (5) | 56 | (21) | 56 | (12) | 64 | (30) | 84 | (1) | 87 | (6) | 90 |
| Mean maximum, | ............ | 34.2 | ............ | 28.0 | ............ | 41.6 | ............ | 62.0 | ............ | 70.8 | ............ | 79.8 |
| Minimum, | (2) | —9 | (10) | —20 | (21) | 13 | (3) | 21 | (22) | 40 | (11) | 45 |
| Mean minimum, | ............ | 15.8 | ............ | 14.4 | ............ | 27.1 | ............ | 39.8 | ............ | 50.6 | ............ | 58.6 |
| Monthly range, | ............ | 65 | ............ | 76 | ............ | 51 | ............ | 63 | ............ | 47 | ............ | 45 |
| **Daily Range.** | | | | | | | | | | | | |
| Greatest, | (3)(4) | 30 | (15) | 34 | (11) | 24 | (23) | 31 | (10, 16) | 30 | (18, 22) | 33 |
| Least, | (22) | 8 | (13) | 3 | (4) | 4 | (2) | 4 | (20) | 5 | (25) | 10 |
| Mean, | ............ | 18.4 | ............ | 13.6 | ............ | 14.5 | ............ | 22.2 | ............ | 20.2 | ............ | 21.2 |
| **Humidity.** | | | | | | | | | | | | |
| Mean relative hum. (per cent.), | ............ | 81.7 | ............ | 84.3 | ............ | 83.4 | ............ | 68.2 | ............ | 75.5 | ............ | 75.2 |
| Mean dew point (Deg. Fahr.), | ............ | 19.8 | ............ | 22.8 | ............ | 28.1 | ............ | 38.6 | ............ | 50.6 | ............ | 59.7 |
| **Precipitation.** | | | | | | | | | | | | |
| Total in inches, | ............ | 2.60 | ............ | 3.42 | ............ | 4.23 | ............ | 1.71 | ............ | 4.77 | ............ | 2.41 |
| Snowfall in inches, | ............ | 12.9 | ............ | 15.1 | ............ | 5.9 | ............ | .4 | ............ | ............ | ............ | ............ |
| Greatest daily precipitation, | (6) | .72 | (26) | 1.26 | (5) | .89 | (7) | .85 | (29) | .98 | (15) | .40 |
| Number of days on which .01 inch or more of rain fell, | ............ | 11 | ............ | 14 | ............ | 16 | ............ | 7 | ............ | 12 | ............ | 13 |
| **Cloudiness.** | | | | | | | | | | | | |
| Mean percentage, | ............ | 44 | ............ | 55 | ............ | 72 | ............ | 31 | ............ | 44 | ............ | 36 |
| Number of days on which cloudiness averaged 80 per cent. or more, | ............ | 8 | ............ | 11 | ............ | 18 | ............ | 3 | ............ | 6 | ............ | 2 |
| **Wind.** | | | | | | | | | | | | |
| Prevailing direction, | ............ | W | ............ | W | ............ | W | ............ | S | ............ | SW | ............ | SW |
| Maximum velocity in miles per hour, | (21) | 17 | (9) | 23 | (7) | 32 | (1) | 25 | (13) | 20 | (15, 29) | 9 |

## *Meteorological Summary for 1899—Continued.*

| | January. | February. | March. | April. | May. | June. |
|---|---|---|---|---|---|---|
| **Miscellaneous Data.** | | | | | | |
| Dates of thunderstorms, | | | | (26) | (1, 2, 3, 16, 17, 18, 29) | (5, 6, 7, 8, 15, 20, 23, 24, 25) |
| Dates of hail, | | | | (26) | | (20, 28) |
| Dates of frost, | 2, 11, 12, 19, 20, 21, 23, 28, 30 | (25, 28) | (6, 14, 11) | (4, 5, 6, 10, 11, 17) | | |
| Dates of aurora, | | | | | | |
| Dates of halos, solar, | | | | | | |
| Dates of halos, lunar, | | | | | | |

*Meteorological Summary for 1899. Monthly Means, Etc. (Figures within parenthesis ( ) indicate the day of the month.)*

| | July. | | August. | | September. | | October. | | November. | | December. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atmospheric Pressure.** | | | | | | | | | | | | |
| Monthly mean, | ............ | 29.988 | ............ | 29.964 | ............ | 30.034 | ............ | 30.192 | ............ | 30.068 | ............ | 30.175 |
| Highest, | (1) | 30.175 | (29) | 30.225 | (15) | 30.3 8 | (2) | 30.509 | (7) | 30.460 | (16) | 30.588 |
| Lowest, | (8) | 29.815 | (21) | 29.771 | (12) | 29.727 | (31) | 29.846 | (30) | 29.708 | (24) | 29.336 |
| Monthly range, | ............ | .360 | ............ | .454 | ............ | .631 | ............ | .663 | ............ | .752 | ............ | 1.252 |
| **Temperature (Deg. Fahr.)** | | | | | | | | | | | | |
| Monthly mean, | ............ | 72.0 | ............ | 71.0 | ............ | 60.4 | ............ | 54.1 | ............ | 40.2 | ............ | 29.8 |
| Maximum, | (23) | 91 | (20) | 96 | (3, 4) | 88 | (15) | 79 | (19, 22) | 60 | (13) | 60 |
| Mean maximum, | ............ | 82.9 | ............ | 82.9 | ............ | 70.5 | ............ | 64.5 | ............ | 47.5 | ............ | 37.0 |
| Minimum, | (1) | 50 | (9) | 47 | (30) | 32 | (3, 22) | 26 | (13) | 22 | (31) | 10 |
| Mean minimum, | ............ | 61.1 | ............ | 59.1 | ............ | 50.3 | ............ | 43.8 | ............ | 32.9 | ............ | 22.7 |
| Monthly range, | ............ | 41 | ............ | 49 | ............ | 56 | ............ | 53 | ............ | 38 | ............ | 50 |
| **Daily Range.** | | | | | | | | | | | | |
| Greatest, | (1, 2) | 31 | (17) | 33 | (4, 5) | 32 | (23) | 34 | (8) | 24 | (12) | 25 |
| Least, | (17) | 5 | (27) | 8 | (20, 30) | 9 | (31) | 5 | (20) | 5 | (24) | 6 |
| Mean, | ............ | 21.7 | ............ | 23.7 | ............ | 20.2 | ............ | 20.7 | ............ | 14.5 | ............ | 14.3 |
| **Humidity.** | | | | | | | | | | | | |
| Mean relative hum. (per cent.), | ............ | 75.6 | ............ | 78.7 | ............ | 80.1 | ............ | 81.1 | ............ | 81.3 | ............ | 80.5 |
| Mean dew point (Deg. Fahr.), | ............ | 63.0 | ............ | 60.9 | ............ | 52.8 | ............ | 45.7 | ............ | 33.8 | ............ | 25.1 |
| **Precipitation.** | | | | | | | | | | | | |
| Total in inches, | ............ | 2.14 | ............ | 2.76 | ............ | 3.84 | ............ | 1.40 | ............ | 3.06 | ............ | 2.53 |
| Snowfall in inches, | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | Trace. | ............ | 2.9 |
| Greatest daily precipitation, | (26) | .54 | (26) | 1.00 | (11) | 1.01 | (31) | .86 | (1) | 1.29 | (12) | 1.19 |
| Number of days on which .01 inch or more of rain fell, | ............ | 9 | ............ | 6 | ............ | 13 | ............ | 6 | ............ | 9 | ............ | 11 |
| **Cloudiness.** | | | | | | | | | | | | |
| Mean percentage, | ............ | 38 | ............ | 37 | ............ | 39 | ............ | 35 | ............ | 50 | ............ | 43 |
| Number of days on which cloudiness averaged 80 per cent. or more, | ............ | 3 | ............ | 4 | ............ | 3 | ............ | 6 | ............ | 5 | ............ | 6 |
| **Wind.** | | | | | | | | | | | | |
| Prevailing direction, | ............ | W | ............ | W | ............ | W | ............ | SW | ............ | W | ............ | SW |
| Maximum velocity in miles per hour, | (30) | 32 | (23) | 34 | (24) | 30 | (16) | 30 | (11) | 15 | (20) | 35 |

## *Meteorological Summary for 1899—Continued.*

| | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|
| **Miscellaneous Data.** | | | | | | |
| Dates of thunderstorms, | (5,6,8,11,16,22) | (2,12,21,25) | (1,3,6,8,25) | | | |
| Dates of hail, | | | | | | |
| Dates of frost, | | | (30) | (1,2,3,4,21,22,30) | (7,9,13,17,21,25,26,27,28) | (2,7,9.14,18.20,21,22,25,26,29,31) |
| Dates of aurora, | | | | | | |
| Dates of halos, solar, | | | | | | |
| Dates of halos, lunar, | | | | | (7) | (9) |

## SUNSHINE RECORDS.

The importance of sunshine in plant development needs no comment. The method adopted by the United States Weather Service, of recording the per cent. of cloudiness at 8 A. M. and 8 P. M., affords only a moderate approximation to the real amount of sunshine; therefore, the desirability of determining more closely the amount of sunshine received by the vegetation of this locality. This was done by means of the apparatus described in an earlier report, by which the image of the sun, as it travels about a spherical reflector, traces a corresponding arc of a circle upon a sensitized paper placed in a camera focussed upon the image in the reflector; any break in the sunshine causes a break of similar duration in the photographed path of the sun's image around the sphere. By this method it is possible to get a record only of the duration of sunshine, and not of the relative intensity.

The observations were in charge of Mr. Norris. They were begun before the sowing season in the spring and were continued to the twenty-second of September. The following table shows the daily duration of the sunshine during this period:

### Sunshine Records for 1899.

| | April. | May. | June. | July. | Aug. | Sept. |
|---|---|---|---|---|---|---|
| | H-M | H-M | H-M | H-M | H-M | H-M |
| 1, | 3-36 | 3-0 | 5-24 | 12-0 | 7-12 | 2-24 |
| 2, | 0-36 | 6-36 | 5-24 | 12-0 | 4-12 | 6-0 |
| 3, | 5-24 | 8-36 | 12-0 | 7-12 | 10-48 | 6-36 |
| 4, | 10-48 | 9-36 | 12-0 | 7-12 | 4-48 | 10-48 |
| 5, | 11-24 | 3-36 | 6-0 | 6-0 | 6-0 | 10-48 |
| 6, | 9-0 | 3-36 | 7-48 | 0-0 | 12-0 | 12-0 |
| 7, | 0-0 | 6-36 | 6-0 | 7-12 | 12-0 | 12-0 |
| 8, | 0-0 | 0-0 | 3-36 | 0-0 | 12-0 | 5-24 |
| 9, | 1-48 | 9-0 | 2-24 | 2-24 | 12-0 | 6-24 |
| 10, | 10-48 | 9-57 | 0-0 | 12-0 | 8-24 | 10-12 |
| 11, | 10-48 | 7-26 | 6-0 | 8-24 | 6-0 | 0-0 |
| 12, | 6-0 | 9-50 | 1-48 | 7-48 | 10-48 | 7-48 |
| 13, | 10-12 | 2-9 | 0-36 | 3-36 | 12-0 | 8-24 |
| 14, | 3-0 | 12-0 | 6-36 | 7-48 | 4-48 | 12-0 |
| 15, | 11-24 | 9-0 | 3-0 | 5-24 | 12-0 | 12-0 |
| 16, | 2-24 | 8-36 | 2-24 | 2-24 | 12-0 | 12-0 |
| 17, | 6-0 | 0-0 | 6-36 | 0-0 | 12-0 | 12-0 |
| 18, | 12-0 | 2-24 | 8-24 | 9-36 | 5-24 | 12-0 |
| 19, | 7-48 | 1-12 | 4-48 | 7-12 | 10-48 | 0-0 |
| 20, | 4-48 | 2-24 | 6-36 | 7-12 | 12-0 | 0-0 |
| 21, | 10-48 | 1-12 | 10-12 | 12-0 | 7-48 | 4-48 |
| 22, | 12-0 | 9-0 | 12-0 | 6-36 | 10-12 | 12-0 |
| 23, | 12-0 | 8-24 | 7-12 | 12-0 | 3-0 | .......... |
| 24, | 9-0 | 9-57 | 4-12 | 4-48 | 12-0 | .......... |
| 25, | 4-48 | 12-0 | 0-36 | 3-0 | 8-24 | .......... |
| 26, | 6-0 | 12-0 | 7-48 | 9-0 | 7-48 | .......... |
| 27, | 9-36 | 1-48 | 12-0 | 12-0 | 0-0 | .......... |
| 28, | 12-0 | 9-36 | 3-36 | 6-0 | 4-48 | .......... |
| 29, | 12-0 | 8-24 | 7-12 | 8-36 | 9-0 | .......... |
| 30, | 6-0 | 11-24 | 8-24 | 4-48 | 6-0 | .......... |
| 31, | .......... | 6-36 | .......... | 12-0 | 4-48 | .......... |
| Means, | 7-24 | 6-19 | 6-1 | 6-48 | 8-13 | 7-54 |

## *Mean Daily Sunshine, 1887-1899 (Hours and Minutes).*

| | 1887. | 1888. | 1889. | 1890. | 1891. | 1892. | 1893. | 1894. | 1895. | 1896. | 1897. | 1899. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H-M | H-M | H-M | H-M | H-M | H-M | H-M | H-M | H-M | H-M | H-M | H-M |
| April, | .......... | 6-54 | .......... | 6-7 | 6-43 | 5-7 | 4-14 | 5-31 | 4-15 | 5-42 | 5-58 | 7-24 |
| May, | .......... | 5-44 | .......... | 5-26 | 5-28 | 5-6 | 5-51 | 4-29 | 6-58 | 4-27 | 5-3 | 6-19 |
| June, | 10-10 | 9-22 | .......... | 9-1 | 8-5 | 7-30 | 6-22 | 5-58 | 5-10 | 4-57 | 6-7 | 6-1 |
| July, | 7-20 | 9-44 | 4-17 | 11-33 | 8-4 | 9-10 | 7-52 | 6-56 | 2-39 | 5-26 | 5-29 | 6-48 |
| August, | 6-45 | 8-18 | 4-50 | 7-41 | 6-2 | 7-38 | 7-44 | 6-29 | 5-39 | 5-15 | 6-50 | 8-13 |
| September, | 4-42 | 4-10 | 2-28 | 5-23 | 7-22 | 6-12 | 3-32 | 4-18 | 5-30 | 5-25 | 7-2 | 7-54 |
| October, | 3-10 | 3-19 | 3-53 | 2-57 | 4-39 | 4-35 | 4-33 | 4-30 | 5-40 | 3-38 | 4-6 | .......... |
| November, | 2-17 | 3-42 | 1-45 | 3-29 | 4-11 | 4-11 | 4-3 | 3-32 | 4-20 | .......... | .......... | .......... |

*Records for 1898 were lost.

## WEEKLY CROP REPORTS.

At the request of the United States Weather Service and the Pennsylvania State Weather Service, the Station has made weekly observations upon the development of the general farm crops as affected by the principal meteorological conditions. These observations were made by Mr. C. W. Norris, under the general supervision of the writer. For the sake of the light they may throw upon the conditions under which the field work of this year has been performed, to aid in comparing climates in different portions of the State and to make a permanent record with which comparison may be made in succeeding years, the reports are tabulated below in much the form in which they were transmitted to the State Weather Service.

The reports were made weekly from April 14 to September 22, the summaries being made up for the week ending at 8 P. M. of the day preceding the date of report.

## *Summary of Weekly Crop Reports for 1899.*

| Report for the Week Ending. | Mean of maximum temperatures. | Mean of minimum temperatures. | Per cent. of sunshine. | Rainfall in inches. | Remarks. |
|---|---|---|---|---|---|
| | De. Fahr. | Deg. Fahr. | | | |
| April 14, | 57.2 | 37.0 | 50.7 | .20 | Wheat in poor condition owing to freezing and thawing during March. Field work late. The frost is out of the ground. Plowing began on about the 12th. |
| April 21, | 67.3 | 43.4 | 66.4 | .09 | The soil is warming up rapidly and is in excellent condition for field work. Oats seeding is well advanced and plowing for corn has commenced. |
| April 28, | 75.6 | 49.7 | 77.9 | .55 | The oats are nearly all sown; some up on the 26th. Plowing for corn is well under way. The rain of the 26th started the meadows growing rapidly. Cherry trees in full bloom and promises a fairly good crop. |
| May 5, | 76.5 | 53.3 | 53.0 | .97 | Meadows are growing rapidly. Corn and potatoes are being planted. Oats are growing rapidly. |
| May 12, | 71.7 | 48.8 | 55.3 | .83 | Crops in general are growing nicely. Some corn is coming up. Oat seeding is about completed. |
| May 19, | 66.4 | 49.0 | 36.1 | 1.89 | All crops are growing very rapidly, especially the grasses owing to the large amount of rain. Corn and potatoes are coming up. |
| May 26, | 65.3 | 45.0 | 65.4 | Trace. | Corn and potatoes are being cultivated. Wheat is beginning to head. All crops are growing rapidly. |
| June 2, | 80.1 | 61.7 | 57.8 | 1.13 | The soil is in good moist condition for cultivation. Wheat is well out in head. Clover is in blossom. |
| June 9, | 83.0 | 62.4 | 59.3 | .45 | The moist condition of the soil and the warm weather is making a good rapid growth of all crops, especially corn, grass and potatoes. |
| June 16, | 76.1 | 58.5 | 24.3 | .40 | Wheat is coloring. Corn is growing fairly well. Oats are looking very well. Clover is about ready for mowing. |
| June 23, | 81.0 | 55.1 | 53.6 | .30 | Clover cutting is well under way, and is an average crop. Oats are heading rapidly. Corn and potatoes are making a good growth. |
| June 30, | 78.4 | 58.0 | 52.1 | 1.21 | The hay crop is nearly all harvested. Some wheat nearly ready to cut. Oats promise a good crop. Corn growing somewhat irregular. |
| July 7, | 85.0 | 60.3 | 70.0 | .03 | Crops are suffering for want of rain. Hay harvest is completed. Wheat is being cut. It is a poor crop owing to the freezing and thawing during the winter and to the fly and joint worm. |
| July 14, | 80.1 | 57.5 | 50.0 | .74 | Wheat is all harvested, some being threshed, yielding about a two-thirds crop. Oats are ripening rapidly. Potatoes are showing signs of early blight. |
| July 21, | 81.3 | 61.7 | 51.1 | .79 | Wheat is being threshed. Corn is making a good growth, some in tassel. Some oats are being harvested; yield of straw large and heads are well filled out. |

| | | | | | |
|---|---|---|---|---|---|
| July 28, | 84.9 | 65.7 | 68.6 | .54 | Corn and potatoes are in need of more rain. Some plowing being done, ground very hard and dry. |
| August 4, | 84.5 | 61.1 | 56.4 | .42 | Oats nearly all hauled in. Ground still very dry. Corn and potatoes very much in need of rain. |
| August 11, | 77.8 | 57.5 | 80.0 | .19 | Oats are above the average crop. Corn and potatoes still suffering from the drought. |
| August 18, | 83.5 | 56.0 | 82.1 | .00 | Late corn is suffering greatly from dry weather. Ground being prepared for wheat under great difficulties on account of dryness of the soil. |
| August 25, | 86.2 | 61.0 | 76.4 | .01 | Corn is filling out poorly on account of dry weather; some being cut to fill silos. Potatoes ripening rapidly. Apples abundant but falling rapidly. Grapes beginning to ripen earlier than usual. |
| September 1, | 77.8 | 60.7 | 41.4 | 2.42 | The recent rains have been a great help to farmers in preparing soil for wheat. Some seeding has been done. |
| September 8, | 83.5 | 58.3 | 75.7 | .84 | Wheat nearly all sown, some coming up. Potatoes are a fair crop; some quite scabby. Apples are falling very fast. Grapes are a good crop. |
| September 15, | 67.7 | 46.8 | 70.0 | 1.01 | Wheat is coming up nicely. Corn is being cut. Meadows are picking up somewhat. First frost August 14th on low lands. |
| September 22, | 69.4 | 51.3 | 62.8 | .34 | Corn is pretty well harvested. Wheat is practically all sown. Potatoes are somewhat less than an average crop; some quite scabby. |

## NOTES ON THE METEOROLOGY OF 1899.

To represent still more completely the seasons of 1899 in their relation to agriculture, a summary is presented below of those data most important from an agricultural standpoint, grouped so as to show the totals for the entire year, for the winter of 1898-99, and for the growing season of 1899, and to this are added a few of the more important indicative facts concerning the season, expressed in terms of the development of the several staple crops.

### *Annual Summary.*

| | |
|---|---|
| Mean barometer for the year (corrected and reduced), | 30.061 inches. |
| Highest barometer for the year (January 2), | 30.816 inches. |
| Lowest barometer for the year (December 24), | 29.336 inches. |
| Mean annual temperature, | 49.1 Deg. Fahr. |
| Highest temperature (August 20), | 96 Deg. Fahr. |
| Lowest temperature (February 10), | —20 Deg. Fahr. |
| Annual range of temperature, | 116 Deg. Fahr. |
| Mean daily range for the year, | 18.8 Deg. Fahr. |
| Greatest daily range (August 17), | 38 Deg. Fahr. |
| Least daily range (February 13), | 3 Deg. Fahr. |
| Mean daily relative humidity, | 78.4 per cent. |
| Annual rainfall, | 34.87 inches. |
| Greatest monthly rainfall (May), | 4.77 inches. |
| Greatest daily rainfall (August 26), | 1.60 inches. |
| Days on which .01 inch or more of rain fell, | 127. |
| Mean percentage of cloudiness, | 43.2 per cent. |
| Days on which cloudiness averaged 80 per cent. or more, | 75. |
| Wind, maximum velocity per hour (March 7), | 32 miles. |

### *Winter of 1898-9, October–March.*

| | |
|---|---|
| Mean temperature, | 23.1 Deg. Fahr. |
| Lowest temperature (February 10), | —20 Deg. Fahr. |
| Total rainfall (rain and melted snow), | 22.11 inches. |
| Total snowfall, | 53.1 inches. |
| Greatest monthly snowfall (December), | 15.4 inches. |
| Greatest daily snowfall (January 6), | 6 inches. |
| Days on which snow fell, | 63. |
| Days on which cloudiness averaged 80 per cent. or more, | 64. |

### *Growing Season of 1899, April–September.*

| | |
|---|---|
| Mean temperature, | 64 Deg. Fahr. |
| Highest temperature (August 20), | 96 Deg. Fahr. |
| Lowest temperature (April 3), | 21 Deg. Fahr. |
| Mean daily range, | 21.5 Deg. Fahr. |
| Greatest daily range (August 17), | 38 Deg. Fahr. |
| Last frost in spring, | April 17th. |
| First frost in fall, | September 30th. |
| Mean relative humidity, | 74.7 per cent. |
| Total rainfall, | 17.63 inches. |
| Greatest daily rainfall (August 26), | 1.60 inches. |
| Days on which .01 inch or more of rain fell, | 60. |
| Mean percentage of cloudiness, | 35.8 per cent. |
| Days on which cloudiness averaged 80 per cent. or more, | 21. |
| Average hours of sunshine per day, | 7 hr.—6 min. |

## *Principal Periods of Crop Development.*

| | |
|---|---|
| **WHEAT:** | |
| Seeded, | Aug. 26—Sept. 2, 1898. |
| In bloom, | May 31, 1899. |
| Ripening, | June 20, 1899. |
| Harvested, | July 1, 1899. |
| **OATS:** | |
| Seeded, | April 18, 1899. |
| Ripening, | July 10, 1899. |
| Harvested, | July 20, 1899. |
| **CORN:** | |
| Planted, | May 1, 1899. |
| Cut, | September 12, 1899. |
| Husking begun, | September 20, 1899. |
| **POTATOES:** | |
| Planted, | May 5, 1899. |
| Harvested (late varieties), | September 12, 1899. |
| **GRASS:** | |
| Cut, | June 30, 1899. |
| **CLOVER:** | |
| In bloom, | June 1, 1899. |
| Cut, | June 20, 1899. |

## TEMPERATURE AND RAINFALL—EXCESSES AND DEFICIENCIES OF WEEKLY AVERAGES.

**In order to meet inquiries frequently made concerning the weather of the current seasons as compared with corresponding brief periods in earlier years, a set of averages by weeks has been prepared from the date for mean daily temperature and rainfall for the years 1883 to 1899, both inclusive, but omitting the year 1885, the data for which were incomplete. The following summary shows the variations of 1899 from the averages for sixteen years, excess and deficiency being respectively indicated by the plus (+) and minus (—) marks prefixed to the figures.**

### *Weekly Averages of Temperature and Rainfall.*

| | Weeks. | Temperature. (Deg. Fahr.) | | | Rainfall. (Inches). | | |
|---|---|---|---|---|---|---|---|
| | | 16 year mean. | 1899. | Excess or deficiency. | 16 year mean. | 1899. | Excess or deficiency. |
| 1 | January 1-7, | 25.7 | 21.5 | —4.2 | .79 | 1.35 | +.56 |
| 2 | January 8-14, | 24.9 | 23.2 | —1.7 | .71 | .25 | —.46 |
| 3 | January 15-21, | 25.7 | 31.7 | +6.0 | .58 | .12 | —.46 |
| 4 | January 22-28, | 25.7 | 28.1 | +2.4 | .68 | .84 | +.16 |
| 5 | January 29—February 4, | 27.4 | 16.8 | —10.6 | .55 | .62 | +.07 |
| 6 | February 5-11, | 26.1 | 7.3 | —18.8 | .90 | .95 | +.05 |
| 7 | February 12-18, | 28.7 | 15.7 | —13.0 | .95 | .58 | —.37 |
| 8 | February 19-25, | 29.6 | 36.2 | +6.6 | .52 | Trace | —.52 |
| 9 | February 26—March 4, | 28.7 | 34.8 | +6.1 | .83 | 1.69 | +.86 |
| 10 | March 5-11, | 32.5 | 33.5 | +1.0 | .65 | .89 | +.24 |
| 11 | March 12-18, | 33.8 | 38.3 | +4.5 | .49 | .86 | +.37 |
| 12 | March 19-25 | 36.7 | 29.8 | —6.9 | .91 | .88 | —.03 |
| 13 | March 26—April 1, | 36.9 | 34.1 | —2.8 | .61 | 1.20 | +.59 |
| 14 | April 2-8, | 41.4 | 34.7 | —6.7 | .52 | .94 | +.42 |
| 15 | April 9-15, | 46.7 | 49.1 | +2.4 | .88 | .12 | —.76 |
| 16 | April 16-22, | 50.9 | 55.9 | +5.0 | .56 | .09 | —.47 |
| 17 | April 23-29, | 55.4 | 64.1 | +8.7 | .51 | .55 | +.04 |
| 18 | April 30—May 6, | 58.2 | 63.8 | +5.6 | .95 | .97 | +.02 |
| 19 | May 7-13, | 59.5 | 61.0 | +1.5 | .74 | .88 | +.14 |
| 20 | May 14-20, | 57.7 | 56.1 | —1.6 | 1.12 | 1.84 | +.72 |
| 21 | May 21-27, | 60.2 | 57.1 | —3.1 | .81 | .04 | —.77 |
| 22 | May 28—June 3, | 64.3 | 70.9 | +6.6 | 1.10 | 1.09 | —.01 |
| 23 | June, 4-10, | 66.7 | 72.1 | +5.4 | .79 | .45 | —.34 |
| 24 | June 11-17, | 67.5 | 67.4 | —.1 | .99 | .40 | —.59 |
| 25 | June 18-24, | 67.5 | 70.3 | +2.8 | 1.06 | .65 | —.41 |
| 26 | June 25—July 1, | 68.7 | 65.9 | —2.8 | 1.08 | .86 | —.22 |
| 27 | July 2-8, | 70.7 | 63.0 | —7.7 | .49 | .56 | +.07 |
| 28 | July 9-15, | 68.6 | 69.1 | +.5 | .86 | .39 | —.47 |
| 29 | July 16-22, | 72.2 | 72.9 | +.7 | .82 | .61 | —.21 |
| 30 | July 23-29, | 70.2 | 74.8 | +4.6 | .98 | .54 | —.44 |
| 31 | July 30—August 5, | 68.9 | 72.9 | +4.0 | .82 | .61 | —.21 |
| 32 | August 6-12, | 69.1 | 69.9 | +.8 | .68 | Trace | —.68 |
| 33 | August 13-19, | 68.6 | 69.9 | +1.3 | .76 | .00 | —.76 |
| 34 | August 20-26, | 67.5 | 73.0 | +5.5 | .91 | 1.61 | +.70 |
| 35 | August 27—September 2, | 67.3 | 69.3 | +2.0 | .79 | .90 | +.11 |
| 36 | September 3-9, | 66.7 | 69.6 | +2.9 | .67 | .76 | +.09 |
| 37 | September 10-16, | 65.5 | 56.4 | —9.1 | .74 | 1.01 | +.27 |
| 38 | September 17-23, | 61.9 | 60.8 | —1.1 | .85 | .38 | —.47 |
| 39 | September 24-30, | 58.3 | 51.6 | —6.7 | .74 | 1.37 | +.63 |
| 40 | October 1-7, | 55.0 | 46.7 | —8.3 | .51 | .00 | —.51 |
| 41 | October 8-14, | 51.3 | 58.1 | +6.8 | .64 | .28 | —.36 |
| 42 | October 15-21, | 49.6 | 56.3 | +6.7 | .29 | .08 | —.21 |
| 43 | October 22-28, | 46.9 | 57.9 | +11.0 | .71 | Trace | —.71 |
| 44 | October 29—November 4, | 55.4 | 43.3 | —12.1 | .69 | 2.66 | +1.97 |
| 45 | November 5-11, | 46.0 | 43.4 | —2.6 | .77 | .61 | —.16 |
| 46 | November 12-18, | 40.2 | 37.3 | —2.9 | .60 | .18 | —.42 |
| 47 | November 19-25, | 38.4 | 42.1 | +3.7 | .57 | .65 | +.08 |
| 48 | November 26—December 2, | 34.7 | 39.0 | +4.3 | .43 | .29 | —.14 |
| 49 | December 3-9, | 30.4 | 30.3 | —.1 | .59 | .13 | —.46 |
| 50 | December 10-16, | 31.8 | 36.1 | +4.3 | .49 | 1.42 | +.93 |
| 51 | December 17-23, | 32.3 | 35.9 | +3.6 | .72 | .14 | —.58 |
| 52 | December 24-31, | 30.8 | 15.5 | —15.3 | .52 | .55 | +.03 |

eficiency in temperature for 1899 is .21 Deg. Fahr.
ficiency in rainfall for 1899 is .07 inches.

## WEATHER SIGNALS.

By arrangement with the State Weather Service and through the courtesy of the Pennsylvania Railroad, the Station is in daily receipt of the weather predictions for Pennsylvania, issued by the United States Weather Bureau. These predictions cover the weather (whether rainy or fair), temperature and wind for the day of issue. To secure a speedy and widespread dissemination of these predictions, the State Weather Service has issued signal flags, by means of which the weather and temperature for thirty-six hours after 7 A. M. of the day for which the prediction has been made, may be indicated. These flags the Station displays from the flag-staff on the top of the College tower, whence they are visible for quite a distance on every side.

# APPENDIX.

## DETAILED METEOROLOGICAL RECORDS

## FOR 1899.

# *Meteorological Records for 1899—Barometric Pressure in Inches—Corrected and Reduced.*

| Dates. | January. | | | February. | | | March. | | | April. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 30.610 | 30.818 | 30.714 | 30.403 | 30.256 | 30.330 | 29.973 | 29.957 | 29.965 | 29.995 | 30.029 | 30.012 |
| 2, | 30.908 | 30.723 | 30.816 | 30.247 | 30.179 | 30.213 | 29.856 | 29.937 | 29.897 | 30.142 | 30.178 | 30.160 |
| 3, | 30.583 | 30.396 | 30.490 | 29.979 | 29.757 | 29.868 | 30.088 | 30.011 | 30.050 | 30.225 | 30.183 | 30.204 |
| 4, | 30.192 | 29.896 | 30.044 | 29.895 | 29.966 | 29.932 | 29.923 | 29.799 | 29.861 | 30.202 | 30.127 | 30.165 |
| 5, | 30.088 | 30.299 | 30.194 | 30.138 | 30.158 | 30.1 8 | 29.385 | 29.730 | 29.558 | 30.294 | 30.287 | 30.291 |
| 6, | 30.088 | 29.681 | 29.885 | 30.128 | 29.929 | 30.029 | 30.019 | 29.804 | 29.912 | 30.396 | 30.191 | 30.294 |
| 7, | 30.225 | 30.335 | 30.280 | 29.955 | 29.815 | 29.885 | 29.756 | 29.927 | 29.842 | 30.086 | 29.595 | 29.841 |
| 8, | 30.481 | 30.241 | 30.361 | 29.642 | 29.802 | 29.722 | 30.338 | 30.302 | 30.320 | 29.644 | 29.702 | 29.678 |
| 9, | 30.236 | 30.219 | 30.228 | 30.041 | 30.289 | 30.165 | 30.115 | 30.063 | 30.089 | 29.833 | 29.972 | 29.903 |
| 10, | 30.555 | 30.679 | 30.617 | 30.517 | 30.566 | 30.542 | 30.330 | 30.225 | 30.278 | 30.119 | 30.107 | 30.113 |
| 11, | 30.798 | 30.659 | 30.729 | 30.700 | 30.557 | 30.629 | 30.210 | 29.963 | 30.087 | 30.293 | 30.055 | 30.174 |
| 12, | 30.548 | 30.421 | 30.485 | 30.497 | 30.352 | 30.425 | 29.743 | 29.747 | 29.745 | 29.958 | 29.952 | 29.955 |
| 13, | 30.304 | 30.158 | 30.231 | 30.070 | 29.855 | 29.963 | 30.217 | 30.330 | 30.274 | 30.042 | 29.818 | 29.930 |
| 14, | 29.803 | 29.852 | 29.828 | 30.247 | 30.399 | 30.323 | 30.424 | 30.312 | 30.368 | 29.746 | 29.904 | 29.825 |
| 15, | 30.032 | 30.091 | 30.062 | 30.483 | 30.367 | 30.425 | 30.090 | 29.688 | 29.885 | 30.082 | 29.936 | 30.009 |
| 16, | 30.090 | 29.823 | 29.958 | 30.340 | 30.009 | 30.175 | 30.082 | 30.211 | 30.147 | 29.842 | 29.958 | 29.900 |
| 17, | 29.857 | 30.035 | 29.946 | 29.983 | 29.943 | 29.963 | 30.318 | 30.091 | 30.205 | 30.125 | 30.030 | 30.078 |
| 18, | 30.207 | 30.389 | 30.298 | 29.894 | 29.735 | 29.815 | 29.814 | 29.537 | 29.676 | 30.136 | 29.957 | 30.047 |
| 19, | 30.484 | 30.347 | 30.416 | 29.737 | 29.755 | 29.746 | 29.136 | 29.576 | 29.356 | 29.981 | 29.945 | 29.963 |
| 20, | 30.253 | 30.130 | 30.192 | 29.637 | 29.651 | 29.644 | 29.901 | 30.204 | 30.053 | 30.100 | 30.030 | 30.065 |
| 21, | 29.989 | 29.706 | 29.848 | 29.708 | 29.510 | 29.609 | 30.368 | 30.129 | 30.249 | 30.086 | 30.127 | 30.107 |
| 22, | 29.815 | 29.980 | 29.898 | 29.521 | 29.695 | 29.608 | 30.026 | 29.858 | 29.942 | 30.259 | 30.175 | 30.217 |
| 23, | 30.102 | 29.930 | 30.016 | 29.749 | 29.889 | 29.819 | 29.782 | 29.915 | 29.849 | 30.213 | 30.068 | 30.141 |
| 24, | 29.698 | 29.523 | 29.611 | 30.274 | 30.406 | 30.340 | 30.028 | 30.057 | 30.043 | 30.083 | 29.988 | 30.036 |
| 25, | 29.870 | 29.960 | 29.915 | 30.504 | 30.431 | 30.468 | 29.988 | 29.571 | 29.780 | 29.981 | 29.913 | 29.947 |
| 26, | 29.809 | 29.529 | 29.669 | 30.253 | 29.939 | 30.096 | 29.789 | 30.028 | 29.909 | 29.958 | 29.916 | 29.937 |
| 27, | 29.982 | 30.150 | 30.066 | 29.873 | 30.024 | 29.949 | 30.182 | 30.074 | 30.128 | 30.056 | 30.074 | 30.065 |
| 28, | 30.059 | 29.853 | 29.956 | 30.115 | 29.724 | 29.910 | 29.838 | 29.387 | 29.613 | 30.166 | 30.085 | 30.126 |
| 29, | 30.018 | 30.064 | 30.072 | ............ | ............ | ............ | 29.596 | 29.683 | 29.640 | 30.171 | 30.097 | 30.134 |
| 30, | 30.065 | 30.093 | 30.079 | ............ | ............ | ............ | 29.898 | 29.784 | 29.841 | 30.117 | 30.002 | 30.059 |
| 31, | 30.132 | 30.008 | 30.065 | ............ | ............ | ............ | 29.679 | 29.833 | 29.756 | ............ | ............ | ............ |
| Means, | 30.193 | 30.128 | 30.160 | 30.090 | 30.084 | 30.082 | 29.927 | 29.964 | 29.946 | 30.077 | 30.013 | 30.045 |

## *Barometric Pressure for 1899—Continued.*

| Dates. | May. | | | June. | | | July. | | | August. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 30.004 | 29.986 | 29.995 | 29.881 | 29.909 | 29.896 | 30.260 | 30.089 | 30.175 | 30.060 | 29.968 | 30.014 |
| 2, | 29.976 | 29.879 | 29.928 | 29.942 | 29.961 | 29.952 | 30.081 | 29.978 | 30.029 | 29.969 | 29.903 | 29.936 |
| 3, | 29.983 | 29.999 | 29.991 | 30.117 | 30.050 | 30.084 | 30.001 | 29.975 | 29.989 | 29.894 | 29.894 | 29.894 |
| 4, | 30.178 | 30.054 | 30.111 | 30.067 | 29.977 | 30.022 | 29.985 | 29.998 | 29.991 | 29.824 | 29.786 | 29.806 |
| 5, | 30.117 | 30.130 | 30.124 | 30.004 | 29.954 | 29.979 | 29.936 | 29.884 | 29.910 | 29.861 | 29.830 | 29.845 |
| 6, | 30.214 | 30.102 | 30.158 | 30.013 | 29.995 | 30.004 | 29.875 | 29.870 | 29.873 | 29.889 | 29.847 | 29.868 |
| 7, | 30.129 | 29.857 | 29.993 | 30.024 | 29.910 | 29.967 | 29.983 | 29.907 | 29.945 | 29.886 | 29.901 | 29.894 |
| 8, | 29.742 | 29.748 | 29.745 | 29.908 | 29.924 | 29.916 | 29.835 | 29.794 | 29.815 | 30.030 | 29.952 | 29.991 |
| 9, | 29.873 | 29.940 | 29.907 | 30.017 | 29.960 | 29.989 | 29.843 | 29.996 | 29.920 | 30.062 | 29.890 | 29.976 |
| 10, | 30.137 | 29.990 | 30.064 | 30.053 | 30.087 | 30.120 | 30.079 | 30.031 | 30.055 | 29.814 | 29.729 | 29.772 |
| 11, | 29.754 | 29.899 | 29.827 | 30.170 | 30.088 | 30.129 | 30.081 | 30.013 | 30.047 | 29.799 | 29.775 | 29.787 |
| 12, | 29.947 | 29.856 | 29.902 | 30.088 | 30.030 | 30.059 | 30.039 | 29.948 | 29.994 | 29.828 | 29.768 | 29.798 |
| | 29.798 | 29.983 | 29.891 | 30.054 | 29.957 | 30.006 | 29.969 | 29.939 | 29.954 | 29.818 | 29.898 | 29.858 |
| 14, | 30.241 | 30.129 | 30.180 | 29.998 | 29.890 | 29.944 | 29.940 | 29.891 | 29.915 | 29.974 | 30.058 | 30.016 |
| 15, | 30.232 | 30.100 | 30.166 | 29.866 | 29.844 | 29.855 | 29.963 | 29.888 | 29.926 | 30.151 | 30.146 | 30.148 |
| 16, | 30.071 | 29.790 | 29.931 | 30.077 | 30.161 | 30.119 | 29.826 | 29.844 | 29.835 | 30.169 | 30.028 | 30.098 |
| 17, | 29.948 | 29.927 | 29.938 | 30.228 | 30.113 | 30.171 | 29.900 | 29.879 | 29.889 | 30.087 | 29.890 | 29.989 |
| 18, | 29.894 | 29.937 | 29.916 | 30.143 | 29.967 | 30.055 | 30.022 | 29.921 | 29.971 | 30.064 | 29.919 | 29.991 |
| 19, | 30.002 | 30.009 | 30.006 | 29.964 | 29.895 | 29.859 | 29.904 | 29.884 | 29.894 | 29.942 | 29.799 | 29.871 |
| 20, | 29.962 | 30.023 | 29.993 | 29.806 | 29.782 | 29.794 | 29.925 | 29.914 | 29.910 | 29.888 | 29.766 | 29.827 |
| 21, | 30.065 | 30.058 | 30.057 | 29.965 | 30.007 | 29.981 | 29.901 | 29.839 | 29.870 | 29.785 | 29.756 | 29.771 |
| 22, | 30.140 | 30.087 | 30.114 | 30.183 | 30.083 | 30.133 | 29.946 | 29.936 | 29.882 | 29.916 | 29.942 | 29.929 |
| 23, | 30.210 | 30.202 | 30.206 | 30.139 | 30.065 | 30.102 | 30.046 | 29.963 | 30.005 | 29.993 | 30.024 | 30.008 |
| 24, | 30.310 | 30.194 | 30.252 | 30.108 | 30.048 | 30.078 | 30.075 | 30.022 | 30.049 | 29.939 | 29.927 | 29.933 |
| 25, | 30.284 | 30.156 | 30.220 | 30.178 | 30.0[illegible]2 | 30.058 | 30.000 | 29.839 | 29.920 | 29.998 | 29.946 | 29.972 |
| 26, | 30.196 | 30.055 | 30.126 | 30.150 | 30.095 | 30.123 | 29.847 | 29.803 | 29.825 | 30.037 | 30.066 | 30.051 |
| 27, | 29.923 | 29.860 | 29.927 | 30.179 | 30.064 | 30.122 | 29.808 | 29.844 | 29.826 | 30.066 | 30.093 | 30.079 |
| 28, | 29.924 | 29.910 | 29.917 | 29.955 | 29.773 | 29.864 | 29.993 | 29.880 | 29.937 | 30.222 | 30.188 | 30.205 |
| 29, | 30.008 | 29.901 | 29.955 | 29.981 | 30.066 | 30.024 | 29.937 | 29.818 | 29.877 | 30.252 | 30.198 | 30.225 |
| 30, | 30.004 | 29.991 | 29.998 | 30.197 | 30.141 | 30.169 | 29.913 | 29.881 | 29.897 | 30.229 | 30.164 | 30.197 |
| 31, | 30.014 | 29.869 | 29.942 | ............ | ............ | ............ | 30.011 | 29.849 | 29.930 | 30.163 | 30.092 | 30.128 |
| Means, | 30.041 | 29.988 | 30.015 | 30.048 | 29.993 | 30.020 | 29.964 | 29.913 | 29.938 | 29.987 | 29.940 | 29.964 |

## *Barometris Pressure for 1899—Continued.*

| Dates. | September. | | | October. | | | November. | | | December. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 30.068 | 30.022 | 30.045 | 30.486 | 30.418 | 30.452 | 29.541 | 29.899 | 29.720 | 29.642 | 29.580 | 29.611 |
| 2, | 30.010 | 29.964 | 29.987 | 30.548 | 30.470 | 30.509 | 30.158 | 30.229 | 30.193 | 29.737 | 29.690 | 29.714 |
| 3, | 29.923 | 29.779 | 29.851 | 30.488 | 30.345 | 30.416 | 30.223 | 30.063 | 30.143 | 29.714 | 29.592 | 29.653 |
| 4, | 30.025 | 30.024 | 30.025 | 30.374 | 30.208 | 30.291 | 30.010 | 30.077 | 30.044 | 29.656 | 29.755 | 29.706 |
| 5, | 30.056 | 29.903 | 29.979 | 30.193 | 30.015 | 30.104 | 30.130 | 30.201 | 30.166 | 30.057 | 30.020 | 30.038 |
| 6, | 29.994 | 30.112 | 30.053 | 29.914 | 29.865 | 29.889 | 30.365 | 30.454 | 30.409 | 30.007 | 30.441 | 30.224 |
| 7, | 30.190 | 30.014 | 30.102 | 30.089 | 30.070 | 30.079 | 30.515 | 30.405 | 30.460 | 30.570 | 30.204 | 30.387 |
| 8, | 29.953 | 29.919 | 29.936 | 30.075 | 29.961 | 30.018 | 30.364 | 30.204 | 30.284 | 30.209 | 30.229 | 30.219 |
| 9, | 30.015 | 30.100 | 30.057 | 30.007 | 30.043 | 30.025 | 30.129 | 29.973 | 30 051 | 30.322 | 30.327 | 30.324 |
| 10, | 30.265 | 30.095 | 30,180 | 30.237 | 30.186 | 30.211 | 29.932 | 29.896 | 29.914 | 30.404 | 30.264 | 30.334 |
| 11, | 29.927 | 29.868 | 29.898 | 30.260 | 30.178 | 30.219 | 29.801 | 29.857 | 29.829 | 30.137 | 29.877 | 30.007 |
| 12, | 29.755 | 29.698 | 29.727 | 30.208 | 30.144 | 30.176 | 30.223 | 30.327 | 30.275 | 29.535 | 29.874 | 29.705 |
| 13, | 29.876 | 29.983 | 29.929 | 30.251 | 30.178 | 30.214 | 30.437 | 30.394 | 30.416 | 29.883 | 30.171 | 30.027 |
| 14, | 30.234 | 30.249 | 30.241 | 30.263 | 30.214 | 30.238 | 30.355 | 30.163 | 30.259 | 30.282 | 30.025 | 30.153 |
| 15, | 30.394 | 30.322 | 30.358 | 30.288 | 30.196 | 30.241 | 30.067 | 29.988 | 30.027 | 30.185 | 30.482 | 30.334 |
| 16, | 30.390 | 30.289 | 30.339 | 30.243 | 30.135 | 30.189 | 30.220 | 30.325 | 30.273 | 30.604 | 30.572 | 30.588 |
| 17, | 30.246 | 30.135 | 30.191 | 30.085 | 29.862 | 29.974 | 30.355 | 30.268 | 30.312 | 30.539 | 30.455 | 30.497 |
| 18, | 30.086 | 29.996 | 30.041 | 29.957 | 29.953 | 29.955 | 30.214 | 30.068 | 30.141 | 30.497 | 30.348 | 30.423 |
| 19, | 29.978 | 29.934 | 29.956 | 30.202 | 30.089 | 30.146 | 29.915 | 29.987 | 29.951 | 30.088 | 30.382 | 30.235 |
| 20, | 29.824 | 29.885 | 29.854 | 30.249 | 30.382 | 30.316 | 30.053 | 30.061 | 30.057 | 30.407 | 30.326 | 30.366 |
| 21, | 29.940 | 30.050 | 29.995 | 30.509 | 30.479 | 30.494 | 30.090 | 29.956 | 30.023 | 30.374 | 30.348 | 30.361 |
| 22, | 30.086 | 30.115 | 30.101 | 30.502 | 30.352 | 30.427 | 29.840 | 29.723 | 29.781 | 30.364 | 30.293 | 30.329 |
| 23, | 30.201 | 30.141 | 30.171 | 30.348 | 30.245 | 30.297 | 29.839 | 30.017 | 29.928 | 30.196 | 29.877 | 30.036 |
| 24, | 30.114 | 29.921 | 30.018 | 30.371 | 30.344 | 30.358 | 30.173 | 30.118 | 30.145 | 29.320 | 29.351 | 29.336 |
| 25, | 29.803 | 29.767 | 29.785 | 30.472 | 30.325 | 30.398 | 30.110 | 30.069 | 30.089 | 29.561 | 29.721 | 29.641 |
| 26, | 29.675 | 29.947 | 29.811 | 30.328 | 30.151 | 30.239 | 30.091 | 29.970 | 30.030 | 29.903 | 30.011 | 29.957 |
| 27, | 30.013 | 30.092 | 30.053 | 30.150 | 30.048 | 30.099 | 29.966 | 29.908 | 29.937 | 30.181 | 30.068 | 30.124 |
| 28, | 30.195 | 30.015 | 30.105 | 29.995 | 29.780 | 29.887 | 29.828 | 29.718 | 29.773 | 30.238 | 30.158 | 30.198 |
| 29, | 29.971 | 30.010 | 29.991 | 29.881 | 30.137 | 30.009 | 29.773 | 29.680 | 29.726 | 30.061 | 30.023 | 30.042 |
| 30, | 30.145 | 30.335 | 30.240 | 30.287 | 30.169 | 30.228 | 29.683 | 29.733 | 29.708 | 29.906 | 29.922 | 29.914 |
| 31, | ............ | ............ | ............ | 30.004 | 29.687 | 29.846 | ............ | ............ | ............ | 29.895 | 29.782 | 29.838 |
| Means, | 30.045 | 30.023 | 30.034 | 30.234 | 30.149 | 30.192 | 30.080 | 30.057 | 30.068 | 30.180 | 30.170 | 30.175 |

*Meteorological Records for 1899—Temperature in Degrees Fahrenheit.*

| Dates. | January<br>8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. | February.<br>8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1, | 5 | 6 | 15 | 1 | 8.0 | 14 | —1 | 13 | 18 | —4 | 7.0 | 22 |
| 2, | 6 | 15 | 17 | —9 | 4.0 | 26 | 3 | 21 | 21 | 6 | 13.5 | 15 |
| 3, | 8 | 24 | 30 | 0 | 15.0 | 30 | 24 | 31 | 31 | 19 | 25.0 | 12 |
| 4, | 42 | 51 | 52 | 22 | 37.0 | 30 | 33 | 27 | 35 | 26 | 30.5 | 9 |
| 5, | 42 | 29 | 56 | 28 | 42.0 | 28 | 20 | 23 | 27 | 19 | 23.0 | 8 |
| 6, | 24 | 32 | 31 | 22 | 26.5 | 9 | 20 | 21 | 23 | 19 | 21.0 | 4 |
| 7, | 12 | 18 | 32 | 5 | 18.5 | 27 | 17 | 19 | 21 | 16 | 18.5 | 5 |
| 8, | 14 | 32 | 33 | 13 | 23.0 | 20 | 14 | 4 | 19 | 3 | 11.0 | 16 |
| 9, | 32 | 35 | 41 | 31 | 36.0 | 10 | —10 | —9 | 4 | —11 | —3.5 | 15 |
| 10, | 13 | 9 | 35 | 8 | 21.5 | 27 | —18 | —10 | —5 | —20 | —12.5 | 15 |
| 11, | —4 | 9 | 13 | —6 | 3.5 | 19 | —11 | 0 | 3 | —16 | —6.5 | 19 |
| 12, | 9 | 23 | 22 | 4 | 13.0 | 18 | —2 | 2 | 3 | —3 | 0 | 6 |
| 13, | 26 | 31 | 31 | 22 | 26.5 | 9 | 1 | 1 | 3 | 0 | 1.5 | 3 |
| 14, | 32 | 39 | 48 | 31 | 39.5 | 17 | 1 | 9 | 15 | 0 | 7.5 | 15 |
| 15, | 36 | 39 | 48 | 36 | 42.0 | 12 | 5 | 26 | 34 | 0 | 17.0 | 34 |
| 16, | 31 | 37 | 46 | 30 | 38.0 | 16 | 10 | 22 | 26 | 6 | 16.0 | 20 |
| 17, | 39 | 33 | 41 | 32 | 36.5 | 9 | 29 | 37 | 41 | 22 | 31.5 | 19 |
| 18, | 26 | 19 | 33 | 19 | 26.0 | 14 | 36 | 36 | 41 | 32 | 36.5 | 9 |
| 19, | 10 | 24 | 35 | 8 | 21.5 | 27 | 33 | 35 | 41 | 34 | 37.5 | 7 |
| 20, | 13 | 32 | 38 | 10 | 24.0 | 28 | 43 | 46 | 52 | 35 | 43.5 | 17 |
| 21, | 30 | 41 | 45 | 23 | 34.0 | 22 | 37 | 47 | 56 | 35 | 45.5 | 21 |
| 22, | 33 | 34 | 41 | 33 | 37.0 | 8 | 44 | 37 | 49 | 37 | 43.0 | 12 |
| 23, | 27 | 40 | 45 | 25 | 35.0 | 20 | 34 | 33 | 39 | 32 | 35.5 | 7 |
| 24, | 36 | 29 | 41 | 29 | 35.0 | 12 | 23 | 23 | 33 | 22 | 27.5 | 11 |
| 25, | 24 | 19 | 29 | 19 | 24.0 | 10 | 20 | 30 | 36 | 16 | 26.0 | 20 |
| 26, | 27 | 34 | 48 | 19 | 33.5 | 29 | 31 | 36 | 36 | 28 | 32.0 | 8 |
| 27, | 12 | 7 | 33 | 7 | 20.0 | 26 | 36 | 30 | 40 | 30 | 35.0 | 10 |
| 28, | 6 | 16 | 20 | 5 | 12.5 | 15 | 26 | 42 | 44 | 21 | 32.5 | 23 |
| 29, | 13 | 8 | 18 | 7 | 12.5 | 11 | ........... | ........... | ........... | ........... | ........... | ........... |
| 30, | 11 | 17 | 23 | 7 | 15.0 | 16 | ........... | ........... | ........... | ........... | ........... | ........... |
| 31, | 9 | 15 | 21 | 8 | 24.5 | 13 | ........... | ........... | ........... | ........... | ........... | ........... |
| Means, | 20.7 | 25.7 | 34.2 | 15.8 | 25.8 | 18.4 | 17.9 | 22.5 | 28.0 | 14.4 | 21.2 | 13.6 |

## *Temperature for 1899—Continued.*

| Dates. | March. | | | | | | April. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maxi-mum. | Mini-mum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maxi-mum. | Mini-mum. | Mean. | Range. |
| 1, | 32 | 37 | 46 | 30 | 28.0 | 16 | 26 | 27 | 36 | 23 | 29.5 | 13 |
| 2, | 36 | 35 | 38 | 32 | 35.0 | 6 | 25 | 25 | 29 | 25 | 27.0 | 4 |
| 3, | 34 | 36 | 40 | 32 | 36.0 | 8 | 26 | 33 | 37 | 21 | 29.0 | 16 |
| 4, | 34 | 36 | 37 | 33 | 35.0 | 4 | 28 | 35 | 43 | 22 | 32.5 | 21 |
| 5, | 37 | 31 | 42 | 30 | 36.0 | 12 | 32 | 47 | 49 | 26 | 37.5 | 23 |
| 6, | 28 | 35 | 40 | 23 | 31.5 | 17 | 32 | 47 | 53 | 26 | 39.5 | 27 |
| 7, | 18 | 28 | 36 | 18 | 27.0 | 18 | 39 | 39 | 47 | 33 | 40.0 | 14 |
| 8, | 22 | 25 | 29 | 19 | 24.0 | 10 | 36 | 36 | 40 | 35 | 37.5 | 5 |
| 9, | 25 | 38 | 39 | 19 | 29.0 | 20 | 33 | 35 | 39 | 33 | 36.0 | 6 |
| 10, | 34 | 40 | 47 | 31 | 39.0 | 16 | 33 | 42 | 50 | 25 | 37.5 | 25 |
| 11, | 38 | 53 | 60 | 36 | 48.0 | 24 | 36 | 51 | 57 | 27 | 42.0 | 30 |
| 12, | 53 | 46 | 64 | 45 | 54.5 | 19 | 46 | 59 | 68 | 45 | 56.5 | 23 |
| 13, | 32 | 32 | 46 | 25 | 35.5 | 21 | 50 | 65 | 77 | 44 | 60.5 | 33 |
| 14, | 32 | 39 | 47 | 26 | 36.5 | 21 | 65 | 58 | 70 | 50 | 60.0 | 20 |
| 15, | 33 | 37 | 39 | 31 | 35.0 | 8 | 48 | 51 | 59 | 43 | 51.0 | 16 |
| 16, | 30 | 30 | 43 | 28 | 35.5 | 15 | 36 | 39 | 56 | 33 | 44.5 | 23 |
| 17, | 24 | 36 | 43 | 20 | 31.5 | 23 | 36 | 55 | 61 | 32 | 46.5 | 29 |
| 18, | 37 | 43 | 44 | 35 | 39.5 | 9 | 48 | 64 | 73 | 37 | 55.0 | 36 |
| 19, | 43 | 26 | 48 | 26 | 37.0 | 22 | 61 | 66 | 75 | 51 | 63.0 | 24 |
| 20, | 23 | 21 | 28 | 21 | 24.5 | 7 | 58 | 64 | 72 | 55 | 63.5 | 17 |
| 21, | 16 | 32 | 33 | 13 | 23.0 | 20 | 55 | 60 | 75 | 53 | 64.0 | 22 |
| 22, | 30 | 37 | 42 | 26 | 34.0 | 16 | 48 | 60 | 70 | 40 | 55.0 | 30 |
| 23, | 34 | 33 | 41 | 30 | 35.5 | 11 | 57 | 68 | 78 | 47 | 62.5 | 31 |
| 24, | 25 | 27 | 33 | 20 | 26.5 | 13 | 61 | 69 | 79 | 51 | 65.0 | 28 |
| 25, | 25 | 31 | 35 | 22 | 28.5 | 13 | 61 | 61 | 78 | 56 | 67.0 | 22 |
| 26, | 32 | 32 | 37 | 30 | 33.5 | 7 | 60 | 65 | 77 | 53 | 65.0 | 24 |
| 27, | 20 | 40 | 47 | 27 | 37.0 | 20 | 58 | 64 | 75 | 50 | 62.5 | 25 |
| 28, | 35 | 37 | 40 | 34 | 37.0 | 6 | 56 | 65 | 72 | 51 | 61.5 | 21 |
| 29, | 22 | 32 | 38 | 21 | 29.5 | 17 | 60 | 70 | 80 | 51 | 65.5 | 29 |
| 30, | 28 | 35 | 43 | 25 | 34.0 | 18 | 67 | 74 | 84 | 56 | 70.0 | 28 |
| 31, | 36 | 36 | 45 | 32 | 38.5 | 13 | ........ | ........ | ........ | ........ | ........ | ........ |
| Means, | 30.9 | 34.7 | 41.6 | 27.1 | 34.3 | 14.5 | 45.9 | 53.4 | 62.0 | 39.8 | 50.9 | 22.2 |

## *Temperature for 1899—Continued.*

| Dates. | May. | | | | | | June. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. |
| 1, | 67 | 62 | 87 | 59 | 73.0 | 28 | 68 | 66 | 83 | 68 | 75.5 | 15 |
| 2, | 67 | 68 | 81 | 58 | 69.5 | 23 | 66 | 72 | 80 | 61 | 70.5 | 19 |
| 3, | 58 | 60 | 71 | 55 | 63.0 | 16 | 60 | 70 | 78 | 52 | 65.0 | 26 |
| 4, | 52 | 58 | 68 | 50 | 59.0 | 18 | 67 | 76 | 84 | 55 | 69.5 | 29 |
| 5, | 52 | 59 | 65 | 44 | 54.5 | 21 | 78 | 78 | 88 | 65 | 76.5 | 23 |
| 6, | 54 | 60 | 69 | 47 | 58.0 | 22 | 75 | 79 | 90 | 71 | 80.5 | 19 |
| 7, | 52 | 68 | 74 | 46 | 60.0 | 28 | 77 | 80 | 87 | 67 | 77.0 | 20 |
| 8, | 61 | 53 | 69 | 52 | 60.5 | 17 | 75 | 71 | 83 | 70 | 76.5 | 13 |
| 9, | 57 | 62 | 71 | 50 | 60.5 | 21 | 60 | 65 | 71 | 57 | 64.0 | 14 |
| 10, | 54 | 62 | 71 | 41 | 56.0 | 30 | 59 | 55 | 67 | 54 | 60.5 | 13 |
| 11, | 53 | 61 | 70 | 52 | 61.0 | 18 | 58 | 65 | 70 | 45 | 57.5 | 25 |
| 12, | 63 | 70 | 78 | 54 | 66.0 | 24 | 65 | 68 | 73 | 60 | 66.5 | 13 |
| 13, | 63 | 59 | 73 | 53 | 63.0 | 20 | 70 | 76 | 82 | 66 | 74.0 | 16 |
| 14, | 53 | 60 | 67 | 43 | 55.0 | 24 | 78 | 77 | 86 | 70 | 78.0 | 16 |
| 15, | 53 | 59 | 67 | 48 | 57.5 | 19 | 79 | 71 | 83 | 63 | 73.0 | 20 |
| 16, | 54 | 60 | 73 | 43 | 58.0 | 30 | 55 | 54 | 72 | 52 | 62.0 | 20 |
| 17, | 56 | 56 | 65 | 54 | 59.5 | 11 | 58 | 65 | 73 | 49 | 61.0 | 24 |
| 18, | 58 | 56 | 64 | 55 | 59.5 | 9 | 62 | 69 | 79 | 47 | 63.0 | 32 |
| 19, | 48 | 48 | 56 | 47 | 51.5 | 9 | 67 | 73 | 81 | 52 | 66.5 | 29 |
| 20, | 50 | 49 | 54 | 49 | 51.5 | 5 | 76 | 69 | 88 | 65 | 76.5 | 23 |
| 21, | 48 | 53 | 57 | 47 | 52.0 | 10 | 64 | 67 | 77 | 57 | 67.0 | 20 |
| 22, | 50 | 54 | 66 | 40 | 53.0 | 26 | 63 | 72 | 81 | 49 | 65.0 | 32 |
| 23, | 51 | 56 | 65 | 44 | 54.5 | 21 | 73 | 77 | 88 | 67 | 77.5 | 21 |
| 24, | 54 | 60 | 70 | 41 | 55.5 | 29 | 74 | 65 | 89 | 64 | 76.5 | 25 |
| 25, | 51 | 60 | 71 | 46 | 58.5 | 25 | 65 | 67 | 73 | 63 | 68.0 | 10 |
| 26, | 60 | 65 | 74 | 48 | 61.0 | 26 | 66 | 67 | 75 | 54 | 64.5 | 21 |
| 27, | 67 | 64 | 74 | 57 | 65.5 | 17 | 61 | 70 | 81 | 50 | 65.5 | 31 |
| 28, | 72 | 75 | 84 | 61 | 72.5 | 23 | 69 | 62 | 80 | 58 | 69.0 | 22 |
| 29, | 72 | 61 | 84 | 62 | 73.0 | 22 | 60 | 64 | 74 | 57 | 65.5 | 17 |
| 30, | 66 | 68 | 78 | 65 | 71.5 | 13 | 63 | 68 | 77 | 50 | 63.5 | 27 |
| 31, | 64 | 68 | 78 | 58 | 68.0 | 20 | ........ | ........ | ........ | ........ | ........ | ........ |
| Means, | 57.2 | 60.4 | 70.8 | 50.6 | 60.7 | 20.2 | 66.9 | 69.3 | 79.8 | 58.6 | 69.2 | 21.2 |

## *Temperature for 1899—Continued.*

| Dates. | July. | | | | | | August. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maxi-mum. | Mini-mum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maxi-mum. | Mini-mum. | Mean. | Range. |
| 1, | 61 | 71 | 81 | 50 | 65.5 | 31 | 66 | 77 | 86 | 55 | 70.5 | 31 |
| 2, | 72 | 78 | 87 | 56 | 71.5 | 31 | 76 | 73 | 84 | 65 | 74.5 | 19 |
| 3, | 75 | 78 | 89 | 62 | 75.5 | 27 | 70 | 76 | 84 | 64 | 74.0 | 20 |
| 4, | 79 | 76 | 89 | 66 | 77.5 | 23 | 68 | 78 | 86 | 65 | 75.5 | 21 |
| 5, | 77 | 74 | 87 | 69 | 78.0 | 18 | 74 | 71 | 84 | 68 | 76.0 | 16 |
| 6, | 70 | 71 | 78 | 62 | 70.0 | 16 | 67 | 71 | 82 | 64 | 73.0 | 18 |
| 7, | 69 | 75 | 84 | 57 | 70.5 | 27 | 63 | 69 | 78 | 51 | 64.5 | 27 |
| 8, | 73 | 64 | 75 | 61 | 68.0 | 14 | 63 | 66 | 78 | 49 | 63.5 | 29 |
| 9, | 61 | 67 | 75 | 52 | 63.5 | 23 | 59 | 70 | 78 | 47 | 62.5 | 21 |
| 10, | 66 | 70 | 81 | 55 | 68.0 | 26 | 72 | 74 | 90 | 61 | 75.5 | 29 |
| 11, | 67 | 72 | 83 | 56 | 69.5 | 27 | 75 | 78 | 85 | 63 | 74.0 | 22 |
| 12, | 65 | 74 | 87 | 57 | 72.0 | 30 | 75 | 81 | 89 | 64 | 76.5 | 25 |
| 13, | 73 | 66 | 80 | 63 | 71.5 | 17 | 79 | 75 | 88 | 62 | 75.0 | 26 |
| 14, | 68 | 71 | 80 | 59 | 69.5 | 21 | 62 | 66 | 75 | 58 | 66.5 | 17 |
| 15, | 70 | 69 | 82 | 57 | 69.5 | 25 | 63 | 67 | 78 | 55 | 66.5 | 23 |
| 16, | 72 | 70 | 84 | 68 | 76.0 | 16 | 63 | 70 | 82 | 48 | 65.0 | 34 |
| 17, | 71 | 66 | 71 | 66 | 68.5 | 5 | 65 | 72 | 87 | 49 | 68.0 | 38 |
| 18, | 65 | 70 | 77 | 58 | 67.5 | 19 | 66 | 77 | 86 | 56 | 71.0 | 30 |
| 19, | 70 | 70 | 81 | 60 | 70.5 | 21 | 75 | 83 | 92 | 65 | 78.5 | 27 |
| 20, | 70 | 70 | 84 | 61 | 72.5 | 23 | 75 | 81 | 96 | 62 | 79.0 | 34 |
| 21, | 74 | 79 | 90 | 62 | 76.0 | 28 | 79 | 71 | 93 | 61 | 77.0 | 32 |
| 22, | 77 | 77 | 90 | 69 | 79.5 | 21 | 70 | 72 | 82 | 61 | 71.5 | 21 |
| 23, | 72 | 78 | 91 | 64 | 77.5 | 27 | 65 | 78 | 74 | 58 | 66.0 | 16 |
| 24, | 72 | 78 | 80 | 69 | 74.5 | 11 | 69 | 73 | 83 | 59 | 71.0 | 24 |
| 25, | 68 | 72 | 77 | 66 | 71.5 | 11 | 70 | 72 | 84 | 61 | 72.5 | 23 |
| 26, | 72 | 79 | 85 | 67 | 76.0 | 18 | 67 | 64 | 87 | 61 | 74.0 | 26 |
| 27, | 77 | 75 | 89 | 65 | 77.0 | 24 | 66 | 65 | 70 | 62 | 66.0 | 8 |
| 28, | 68 | 75 | 82 | 60 | 71.0 | 22 | 62 | 67 | 71 | 58 | 64.5 | 13 |
| 29, | 71 | 81 | 88 | 64 | 76.0 | 24 | 57 | 68 | 78 | 52 | 65.0 | 26 |
| 30, | 64 | 68 | 82 | 61 | 71.5 | 21 | 68 | 68 | 79 | 64 | 71.5 | 15 |
| 31, | 65 | 73 | 82 | 54 | 68.0 | 28 | 72 | 72 | 80 | 66 | 73.0 | 14 |
| Means. | 70.1 | 72.6 | 82.9 | 61.1 | 72.0 | 21.7 | 68.4 | 72.5 | 82.9 | 59.1 | 71.0 | 23.7 |

## *Temperature for 1899—Continued.*

| Dates. | September. | | | | | | October. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean | Range. |
| 1, | 72 | 70 | 80 | 62 | 71.0 | 18 | 37 | 42 | 51 | 31 | 41.0 | 20 |
| 2, | 72 | 73 | 83 | 65 | 74 0 | 18 | 33 | 39 | 50 | 28 | 39.0 | 22 |
| 3, | 69 | 80 | 88 | 63 | 75.5 | 25 | 32 | 42 | 57 | 26 | 41.5 | 31 |
| 4, | 59 | 62 | 88 | 56 | 72.0 | 32 | 42 | 56 | 67 | 34 | 50.5 | 33 |
| 5, | 61 | 74 | 82 | 50 | 66.0 | 32 | 42 | 55 | 64 | 39 | 51.5 | 25 |
| 6, | 74 | 67 | 82 | 67 | 74.5 | 15 | 50 | 52 | 61 | 49 | 55.0 | 12 |
| 7, | 57 | 67 | 77 | 49 | 63.0 | 28 | 44 | 51 | 60 | 37 | 48.5 | 23 |
| 8, | 74 | 65 | 85 | 58 | 71.5 | 27 | 48 | 50 | 53 | 43 | 48.0 | 10 |
| 9, | 62 | 62 | 71 | 58 | 61.5 | 13 | 50 | 53 | 61 | 49 | 55.0 | 12 |
| 10, | 53 | 63 | 70 | 46 | 58.0 | 24 | 41 | 62 | 70 | 39 | 54.5 | 31 |
| 11, | 55 | 55 | 64 | 54 | 59.0 | 10 | 50 | 64 | 70 | 48 | 59.0 | 22 |
| 12, | 60 | 65 | 75 | 47 | 61.0 | 28 | 60 | 64 | 73 | 59 | 66.0 | 14 |
| 13, | 56 | 54 | 65 | 44 | 54.5 | 21 | 50 | 64 | 76 | 48 | 62.0 | 28 |
| 14, | 47 | 53 | 61 | 41 | 51.0 | 20 | 55 | 65 | 76 | 49 | 62.5 | 27 |
| 15, | 44 | 57 | 68 | 38 | 53.0 | 30 | 52 | 67 | 79 | 48 | 63.5 | 31 |
| 16, | 50 | 64 | 72 | 44 | 58.0 | 28 | 57 | 64 | 68 | 51 | 59.5 | 17 |
| 17, | 63 | 66 | 76 | 55 | 65.5 | 21 | 57 | 64 | 65 | 57 | 61.0 | 8 |
| 18, | 62 | 67 | 74 | 53 | 63.5 | 21 | 59 | 61 | 69 | 58 | 63.5 | 11 |
| 19, | 60 | 62 | 67 | 56 | 61.5 | 11 | 51 | 57 | 69 | 48 | 58.5 | 21 |
| 20, | 61 | 58 | 66 | 57 | 61.5 | 9 | 48 | 42 | 59 | 42 | 50.5 | 17 |
| 21, | 54 | 52 | 62 | 52 | 57.0 | 10 | 36 | 37 | 47 | 28 | 37.5 | 19 |
| 22, | 55 | 58 | 69 | 42 | 55.5 | 27 | 32 | 49 | 52 | 26 | 39.0 | 26 |
| 23, | 55 | 63 | 70 | 52 | 61.0 | 18 | 44 | 65 | 74 | 40 | 57.0 | 34 |
| 24, | 62 | 67 | 70 | 52 | 61.0 | 18 | 63 | 68 | 77 | 59 | 68.0 | 18 |
| 25, | 63 | 57 | 72 | 56 | 61.0 | 16 | 49 | 53 | 68 | 49 | 58.5 | 19 |
| 26, | 50 | 43 | 57 | 40 | 48.5 | 17 | 45 | 64 | 73 | 45 | 59.0 | 28 |
| 27, | 45 | 48 | 55 | 40 | 47.5 | 15 | 53 | 66 | 74 | 49 | 61.5 | 25 |
| 28, | 45 | 60 | 66 | 37 | 51.5 | 29 | 57 | 68 | 70 | 54 | 62.0 | 16 |
| 29, | 56 | 45 | 60 | 45 | 52.5 | 15 | 54 | 48 | 68 | 48 | 58.0 | 20 |
| 30, | 39 | 37 | 41 | 32 | 36.5 | 9 | 37 | 46 | 52 | 36 | 44.0 | 16 |
| 31, | ........ | ........ | ........ | ........ | ........ | ........ | 46 | 43 | 46 | 41 | 43.5 | 5 |
| Means, | 57.8 | 60.4 | 70.5 | 50.3 | 60.4 | 20.2 | 47.6 | 55.5 | 64.5 | 42.8 | 54.1 | 20.7 |

## *Temperature for 1899—Continued.*

| Dates. | July. | | | | | | August. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maxi-mum. | Mini-mum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maxi-mum. | Mini-mum. | Mean. | Range. |
| 1, | 61 | 71 | 81 | 50 | 65.5 | 31 | 66 | 77 | 86 | 55 | 70.5 | 31 |
| 2, | 72 | 78 | 87 | 56 | 71.5 | 31 | 76 | 73 | 84 | 65 | 74.5 | 19 |
| 3, | 75 | 78 | 89 | 62 | 75.5 | 27 | 70 | 76 | 84 | 64 | 74.0 | 20 |
| 4, | 79 | 76 | 89 | 66 | 77.5 | 23 | 68 | 78 | 86 | 65 | 75.5 | 21 |
| 5, | 77 | 74 | 87 | 69 | 78.0 | 18 | 74 | 71 | 84 | 68 | 76.0 | 16 |
| 6, | 70 | 71 | 78 | 62 | 70.0 | 16 | 67 | 71 | 82 | 64 | 73.0 | 18 |
| 7, | 69 | 75 | 84 | 57 | 70.5 | 27 | 68 | 69 | 78 | 51 | 64.5 | 27 |
| 8, | 73 | 64 | 75 | 61 | 68.0 | 14 | 62 | 66 | 78 | 49 | 63.5 | 29 |
| 9, | 61 | 67 | 75 | 52 | 63.5 | 23 | 59 | 70 | 78 | 47 | 62.5 | 21 |
| 10, | 66 | 70 | 81 | 55 | 68.0 | 26 | 72 | 74 | 90 | 61 | 75.5 | 29 |
| 11, | 67 | 72 | 83 | 56 | 69.5 | 27 | 75 | 78 | 85 | 63 | 74.0 | 22 |
| 12, | 65 | 74 | 87 | 57 | 72.0 | 30 | 75 | 81 | 89 | 64 | 76.5 | 25 |
| 13, | 73 | 66 | 80 | 63 | 71.5 | 17 | 79 | 75 | 88 | 62 | 75.0 | 26 |
| 14, | 68 | 71 | 80 | 59 | 69.5 | 21 | 62 | 66 | 75 | 58 | 66.5 | 17 |
| 15, | 70 | 69 | 82 | 57 | 69.5 | 25 | 68 | 67 | 78 | 55 | 66.5 | 23 |
| 16, | 72 | 70 | 84 | 68 | 76.0 | 16 | 63 | 70 | 82 | 48 | 65.0 | 34 |
| 17, | 71 | 66 | 71 | 66 | 68.5 | 5 | 65 | 72 | 87 | 49 | 68.0 | 38 |
| 18, | 65 | 70 | 77 | 58 | 67.5 | 19 | 66 | 77 | 86 | 56 | 71.0 | 30 |
| 19, | 70 | 70 | 81 | 60 | 70.5 | 21 | 75 | 83 | 92 | 65 | 78.5 | 27 |
| 20, | 70 | 70 | 84 | 61 | 72.5 | 23 | 76 | 81 | 96 | 62 | 79.0 | 34 |
| 21, | 74 | 79 | 90 | 62 | 76.0 | 28 | 79 | 71 | 93 | 61 | 77.0 | 32 |
| 22, | 77 | 77 | 90 | 69 | 79.5 | 21 | 70 | 72 | 82 | 61 | 71.5 | 21 |
| 23, | 72 | 78 | 91 | 64 | 77.5 | 27 | 65 | 78 | 74 | 58 | 66.0 | 16 |
| 24, | 72 | 73 | 80 | 69 | 74.5 | 11 | 69 | 73 | 83 | 59 | 71.0 | 24 |
| 25, | 68 | 72 | 77 | 66 | 71.5 | 11 | 70 | 72 | 84 | 61 | 72.5 | 23 |
| 26, | 72 | 79 | 85 | 67 | 76.0 | 18 | 67 | 64 | 87 | 61 | 74.0 | 26 |
| 27, | 77 | 75 | 89 | 65 | 77.0 | 24 | 66 | 65 | 70 | 62 | 66.0 | 8 |
| 28, | 68 | 75 | 82 | 60 | 71.0 | 22 | 62 | 67 | 71 | 58 | 64.5 | 13 |
| 29, | 71 | 81 | 88 | 64 | 76.0 | 24 | 57 | 68 | 78 | 52 | 65.0 | 26 |
| 30, | 64 | 68 | 82 | 61 | 71.5 | 21 | 68 | 68 | 79 | 64 | 71.5 | 15 |
| 31, | 65 | 73 | 82 | 54 | 68.0 | 28 | 72 | 72 | 80 | 66 | 73.0 | 14 |
| Means, | 70.1 | 72.6 | 82.9 | 61.1 | 72.0 | 21.7 | 68.4 | 72.5 | 82.9 | 59.1 | 71.0 | 23.7 |

## *Temperature for 1899—Continued.*

| Dates. | September. | | | | | | October. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean | Range. |
| 1, | 72 | 70 | 80 | 62 | 71.0 | 18 | 37 | 42 | 51 | 31 | 41.0 | 20 |
| 2, | 72 | 73 | 83 | 65 | 74.0 | 18 | 33 | 39 | 50 | 28 | 39.0 | 22 |
| 3, | 69 | 80 | 88 | 63 | 75.5 | 25 | 32 | 42 | 57 | 26 | 41.5 | 31 |
| 4, | 59 | 62 | 88 | 56 | 72.0 | 32 | 42 | 56 | 67 | 34 | 50.5 | 33 |
| 5, | 61 | 74 | 82 | 50 | 66.0 | 32 | 42 | 55 | 64 | 39 | 51.5 | 25 |
| 6, | 74 | 67 | 82 | 67 | 74.5 | 15 | 50 | 52 | 61 | 49 | 55.0 | 12 |
| 7, | 57 | 67 | 77 | 49 | 63.0 | 28 | 44 | 51 | 60 | 37 | 48.5 | 23 |
| 8, | 74 | 65 | 85 | 58 | 71.5 | 27 | 48 | 50 | 53 | 43 | 48.0 | 10 |
| 9, | 62 | 62 | 71 | 58 | 64.5 | 13 | 50 | 53 | 61 | 49 | 55.0 | 12 |
| 10, | 53 | 63 | 70 | 46 | 58.0 | 24 | 41 | .62 | 70 | 39 | 54.5 | 31 |
| 11, | 55 | 55 | 64 | 54 | 59.0 | 10 | 50 | 64 | 70 | 48 | 59.0 | 22 |
| 12, | 60 | 65 | 75 | 47 | 61.0 | 28 | 60 | 64 | 73 | 59 | 66.0 | 14 |
| 13, | 56 | 54 | 65 | 44 | 54.5 | 21 | 50 | 64 | 76 | 48 | 62.0 | 28 |
| 14, | 47 | 53 | 61 | 41 | 51.0 | 20 | 55 | 65 | 76 | 49 | 62.5 | 27 |
| 15, | 44 | .57 | 68 | 38 | 53.0 | 30 | 52 | 67 | 79 | 48 | 63.5 | 31 |
| 16, | 50 | 64 | 72 | 44 | 58.0 | 28 | 57 | 64 | 68 | 51 | 59.5 | 17 |
| 17, | 63 | 66 | 76 | 55 | 65.5 | 21 | 57 | 64 | 65 | 57 | 61.0 | 8 |
| 18, | 62 | 67 | 74 | 53 | 63.5 | 21 | 59 | 61 | 69 | 58 | 63.5 | 11 |
| 19, | 60 | 62 | 67 | 56 | 61.5 | 11 | 51 | 57 | 69 | 48 | 58.5 | 21 |
| 20, | 61 | 58 | 66 | 57 | 61.5 | 9 | 48 | 42 | 59 | 42 | 50.5 | 17 |
| 21, | 54 | 52 | 62 | 52 | 57.0 | 10 | 36 | 37 | 47 | 28 | 37.5 | 19 |
| 22, | 55 | 58 | 69 | 42 | 55.5 | 27 | 32 | 49 | 52 | 26 | 39.0 | 26 |
| 23, | 55 | 63 | 70 | 52 | 61.0 | 18 | 44 | 65 | 74 | 40 | 57.0 | 34 |
| 24, | 62 | 67 | 70 | 52 | 61.0 | 18 | 63 | 68 | 77 | 59 | 68.0 | 18 |
| 25, | 63 | 57 | 72 | 56 | 64.0 | 16 | 49 | 53 | 68 | 49 | 58.5 | 19 |
| 26, | 50 | 43 | 57 | 40 | 48.5 | 17 | 45 | 64 | 73 | 45 | 59.0 | 28 |
| 27, | 45 | 48 | 55 | 40 | 47.5 | 15 | 53 | 66 | 74 | 49 | 61.5 | 25 |
| 28, | 45 | 60 | 66 | 37 | 51.5 | 29 | 57 | 68 | 70 | 54 | 62.0 | 16 |
| 29, | 56 | 45 | 60 | 45 | 52.5 | 15 | 54 | 48 | 68 | 48 | 58.0 | 20 |
| 30, | 39 | 37 | 41 | 32 | 36.5 | 9 | 37 | 46 | 52 | 36 | 44.0 | 16 |
| 31, | ........... | ........... | ........... | ........... | ........... | ........... | 46 | 43 | 46 | 41 | 43.5 | 5 |
| Means, | 57.8 | 60.4 | 70.5 | 50.3 | 60.4 | 20.2 | 47.6 | 55.5 | 64.5 | 42.8 | 54.1 | 20.7 |

### *Temperature for 1899—Continued.*

| Dates. | November. | | | | | | December. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. | 8 A. M. | 8 P. M. | Maximum. | Minimum. | Mean. | Range. |
| 1, | 45 | 48 | 52 | 38 | 45.0 | 14 | 43 | 46 | 51 | 37 | 44.0 | 14 |
| 2, | 39 | 35 | 48 | 35 | 41.5 | 13 | 34 | 42 | 47 | 33 | 40.0 | 14 |
| 3, | 36 | 36 | 40 | 32 | 36.0 | 8 | 38 | 39 | 50 | 36 | 43.0 | 14 |
| 4, | 36 | 37 | 40 | 30 | 35.0 | 10 | 33 | 30 | 40 | 26 | 33.0 | 14 |
| 5, | 37 | 40 | 45 | 34 | 39.5 | 11 | 22 | 23 | 30 | 21 | 25.5 | 9 |
| 6, | 37 | 36 | 45 | 35 | 40.0 | 10 | 27 | 19 | 30 | 19 | 24.5 | 11 |
| 7, | 31 | 38 | 49 | 27 | 38.0 | 22 | 10 | 29 | 30 | 10 | 20.0 | 20 |
| 8, | 32 | 44 | 55 | 31 | 43.0 | 24 | 36 | 36 | 42 | 22 | 32.0 | 20 |
| 9, | 37 | 47 | 56 | 36 | 46.0 | 20 | 30 | 33 | 42 | 27 | 34.5 | 15 |
| 10, | 49 | 48 | 56 | 46 | 51.0 | 10 | 34 | 38 | 42 | 27 | 34.5 | 15 |
| 11, | 44 | 43 | 52 | 41 | 46.5 | 11 | 44 | 55 | 55 | 37 | 46.0 | 18 |
| 12, | 32 | 32 | 43 | 31 | 37.0 | 12 | 52 | 43 | 60 | 35 | 47.5 | 25 |
| 13, | 24 | 30 | 35 | 22 | 28.5 | 13 | 43 | 33 | 45 | 31 | 38.0 | 14 |
| 14, | 26 | 32 | 33 | 24 | 28.5 | 9 | 30 | 33 | 37 | 27 | 32.0 | 10 |
| 15, | 34 | 46 | 47 | 32 | 39.5 | 15 | 29 | 23 | 38 | 22 | 30.0 | 16 |
| 16, | 43 | 38 | 49 | 38 | 43.5 | 11 | 23 | 28 | 29 | 21 | 25.0 | 8 |
| 17, | 36 | 42 | 45 | 32 | 38.5 | 13 | 27 | 33 | 37 | 23 | 30.0 | 14 |
| 18, | 43 | 47 | 52 | 40 | 46.0 | 12 | 29 | 47 | 48 | 26 | 37.0 | 22 |
| 19, | 53 | 45 | 60 | 40 | 50.0 | 20 | 50 | 33 | 51 | 33 | 42.0 | 18 |
| 20, | 42 | 40 | 45 | 40 | 42.5 | 5 | 28 | 33 | 39 | 28 | 33.5 | 11 |
| 21, | 29 | 41 | 49 | 28 | 38.5 | 21 | 31 | 39 | 49 | 28 | 38.5 | 21 |
| 22, | 41 | 54 | 60 | 38 | 49.0 | 22 | 31 | 35 | 47 | 31 | 39.0 | 16 |
| 23, | 38 | 34 | 53 | 34 | 43.5 | 19 | 24 | 38 | 40 | 23 | 31.5 | 17 |
| 24, | 35 | 33 | 42 | 31 | 36.5 | 11 | 33 | 29 | 33 | 27 | 30.0 | 6 |
| 25, | 33 | 33 | 43 | 27 | 35.0 | 16 | 16 | 14 | 28 | 13 | 20.5 | 15 |
| 26, | 33 | 38 | 46 | 29 | 37.5 | 17 | 8 | 13 | 12 | 7 | 9.5 | 5 |
| 27, | 28 | 31 | 38 | 26 | 32.0 | 12 | 14 | 21 | 19 | 8 | 13.5 | 11 |
| 28, | 29 | 35 | 42 | 24 | 33.0 | 18 | 13 | 16 | 24 | 12 | 18.0 | 12 |
| 29, | 37 | 43 | 52 | 31 | 41.5 | 21 | 10 | 11 | 28 | 10 | 19.0 | 18 |
| 30, | 42 | 45 | 53 | 37 | 45.0 | 16 | 11 | 3 | 11 | 3 | 7.0 | 8 |
| 31, | ........ | ........ | ........ | ........ | ........ | ........ | 4 | 7 | 13 | 0 | 6.5 | 13 |
| Means, | 36.7 | 39.7 | 47.5 | 32.9 | 40.2 | 14.5 | 27.6 | 29.6 | 37.0 | 22.7 | 29.8 | 14.3 |

## *Meteorological Records for 1899 --Precipitation in Inches—(Rain and Snow.)*

| Dates. | January. | | February. | | March. | | April. | | May. |
|---|---|---|---|---|---|---|---|---|---|
| | Total precipitation. | Snow. | Total precipitation. | Snow. | Total precipitation. | Snow. | Total precipitation. | Snow. | Total precipitation. |
| 1, | .43 | 4.3 | Trace | Trace | 00 | 00 | .01 | .1 | .72 |
| 2, | 00 | 00 | 00 | 00 | .26 | 00 | Trace | Trace | .13 |
| 3, | 00 | 00 | .19 | Trace | 00 | 00 | .01 | .1 | .12 |
| 4, | 00 | 00 | .42 | Trace | .15 | 00 | 00 | 00 | Trace |
| 5, | .20 | Trace | .30 | 3.0 | .89 | Trace | 00 | 00 | 00 |
| 6, | .72 | 6.0 | .11 | 1.1 | 00 | 00 | 00 | 00 | 00 |
| 7, | Trace | Trace | .21 | 2.1 | Trace | Trace | .85 | .2 | 00 |
| 8, | 00 | 00 | .32 | 3.2 | 00 | 00 | .08 | 00 | .38 |
| 9, | Trace | Trace | 00 | 00 | Trace | 00 | 00 | 00 | Trace |
| 10, | Trace | Trace | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| 11, | 00 | 00 | .01 | .1 | 00 | 00 | 00 | 00 | .45 |
| 12, | 00 | 00 | .12 | 1.2 | .11 | 00 | .12 | 00 | 00 |
| 13, | .07 | Trace | .29 | 2.9 | 00 | 00 | 00 | 00 | .05 |
| 14, | .18 | 00 | .02 | .2 | 00 | 00 | Trace | 00 | 00 |
| 15, | 00 | 00 | 00 | 00 | .30 | 00 | 00 | 00 | 00 |
| 16, | .12 | 00 | .11 | 1.0 | Trace | Trace | .09 | 00 | .69 |
| 17, | .03 | 00 | .04 | .3 | 00 | 00 | 00 | 00 | .97 |
| 18, | 00 | 00 | Trace | 00 | .45 | 00 | 00 | 00 | .18 |
| 19, | 00 | 00 | Trace | Trace | .25 | .2 | 00 | 00 | Trace |
| 20, | 00 | 00 | 00 | 00 | Trace | Trace | 00 | 00 | 00 |
| 21, | 00 | 00 | 00 | 00 | .02 | .2 | 00 | 00 | 00 |
| 22, | .01 | .1 | Trace | 00 | .32 | 2.5 | 00 | 00 | Trace |
| 23, | 00 | 00 | Trace | Trace | .13 | Trace | 00 | 00 | Trace |
| 24, | .60 | .1 | Trace | Trace | Trace | Trace | 00 | 00 | 00 |
| 25, | .23 | 2.3 | 00 | 00 | .16 | 1.6 | Trace | 00 | 00 |
| 26, | Trace | Trace | 1.26 | 00 | .19 | 1.0 | .55 | 00 | 00 |
| 27, | Trace | Trace | .02 | 00 | 00 | 00 | 00 | 00 | .04 |
| 28, | 00 | 00 | 00 | 00 | .77 | 00 | 00 | 00 | 00 |
| 29, | Trace | Trace | ............ | ............ | .20 | .3 | 00 | 00 | .98 |
| 30, | Trace | Trace | ............ | ............ | .01 | .1 | Trace | 00 | Trace |
| 31, | .01 | .1 | ............ | ............ | .02 | 00 | ............ | ............ | .06 |
| Total, | 2.60 | 12.9 | 3.42 | 15.1 | 4.23 | 5.9 | 1.71 | .4 | 4.77 |

## *Precipitation for 1899—Continued.*

| Dates. | June. | July. | August. | Sept. | October. | November. | | December. | |
|---|---|---|---|---|---|---|---|---|---|
| | Total precipitation. | Total precipitation. | Total precipitation. | Total precipitation. | Total precipitation. | Total precipitation. | Snow. | Total precipitation. | Snow. |
| 1, | .05 | 00 | 00 | .24 | 00 | 1.29 | 00 | .29 | 00 |
| 2, | Trace | 00 | Trace | .08 | 00 | 00 | 00 | 00 | 00 |
| 3, | 00 | 00 | 00 | .01 | 00 | .27 | Trace | .01 | 00 |
| 4, | 00 | 00 | .38 | 00 | 00 | .06 | Trace | .06 | .2 |
| 5, | .10 | Trace | .19 | 00 | 00 | Trace | 00 | .03 | .3 |
| 6, | .07 | .03 | 00 | .02 | 00 | Trace | 00 | .03 | .3 |
| 7, | .15 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| 8, | .04 | .53 | 00 | .73 | .19 | 00 | 00 | 00 | 00 |
| 9, | .09 | Trace | 00 | 00 | .09 | 00 | 00 | 00 | 00 |
| 10, | 00 | 00 | 00 | 00 | 00 | 00 | 00 | Trace | 00 |
| 11, | 00 | 00 | Trace | 1.01 | 00 | .61 | 00 | .07 | 00 |
| 12, | Trace | .05 | 00 | 00 | 00 | 00 | 00 | 1.19 | 00 |
| 13, | 00 | Trace | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| 14, | 00 | .16 | 00 | 00 | 00 | .12 | Trace | .01 | .1 |
| 15, | .40 | .18 | 00 | 00 | 00 | .04 | 00 | .15 | Trace |
| 16, | 00 | .46 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| 17, | 00 | .15 | 00 | 00 | .03 | 00 | 00 | 00 | 00 |
| 18, | 00 | 00 | 00 | 00 | .05 | .02 | 00 | 00 | 00 |
| 19, | .04 | Trace | 00 | .21 | 00 | .05 | 00 | .14 | 00 |
| 20, | .26 | 00 | 00 | .07 | 00 | 00 | 00 | 00 | 00 |
| 21, | 00 | 00 | Trace | .06 | 00 | 00 | 00 | 00 | 00 |
| 22, | 00 | 00 | .01 | 00 | Trace | Trace | 00 | 00 | 00 |
| 23, | Trace | 00 | 00 | .04 | 00 | .60 | 00 | 00 | 00 |
| 24, | .35 | 00 | 00 | 00 | 00 | 00 | 00 | .55 | 2.0 |
| 25, | .27 | 00 | 00 | .70 | 00 | 00 | 00 | Trace | Trace |
| 26, | 00 | .54 | 1.60 | .30 | 00 | 00 | 00 | 00 | 00 |
| 27, | 00 | Trace | .19 | 00 | 00 | 00 | 00 | 00 | 00 |
| 28, | .21 | 00 | .39 | 00 | 00 | 00 | 00 | 00 | 00 |
| 29, | .38 | 00 | 00 | .37 | .18 | 00 | 00 | Trace | Trace |
| 30, | 00 | 04 | Trace | 00 | 00 | 00 | 00 | Trace | Trace |
| 31, | ............ | 00 | 00 | ............ | .86 | ............ | ............ | 00 | 00 |
| Total, | 2.41 | 2.14 | 2.76 | 3.84 | 1.40 | 3.06 | Trace | 2.53 | 2.9 |

## *Meteorological Records for 1899—Dew Points (in Degrees Fahrenheit.)*

| Dates. | January. | | | February. | | | March. | | | April. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | —1 | 0 | —0.5 | .... | .... | .... | 25 | 29 | 27.0 | 23 | 24 | 23.5 |
| 2, | 0 | 6 | 3.0 | 18 | 18 | 18.0 | 34 | 32 | 33.0 | 22 | 22 | 22.0 |
| 3, | 3 | 21 | 12.0 | 21 | 29 | 25.0 | 34 | 35 | 34.5 | 23 | 21 | 22.0 |
| 4, | 38 | 45 | 41.5 | 30 | 22 | 26.0 | 32 | 33 | 32.5 | 22 | 24 | 23.0 |
| 5, | 35 | 23 | 29.0 | 20 | 21 | 20.5 | 36 | 25 | 30.5 | 23 | 39 | 31.0 |
| 6, | 24 | 29 | 26.5 | 20 | 21 | 20.5 | 22 | 24 | 23.0 | 23 | 39 | 31.0 |
| 7, | 7 | 14 | 10.5 | 19 | 19 | 19.0 | 14 | 22 | 18.0 | 34 | 38 | 36.0 |
| 8, | 10 | 23 | 16.5 | 14 | 4 | 9.0 | 15 | 18 | 16.5 | 31 | 31 | 31.0 |
| 9, | 27 | 30 | 28.5 | .... | .... | .... | 22 | 33 | 27.5 | 28 | 24 | 26.0 |
| 10, | 7 | 4 | 5.5 | .... | .... | .... | 29 | 33 | 31.0 | 26 | 26 | 26.0 |
| 11, | .... | .... | .... | .... | .... | .... | 33 | 43 | 38.0 | 28 | 36 | 32.0 |
| 12, | 20 | 20 | 20.0 | .... | .... | .... | 47 | 32 | 39.5 | 44 | 39 | 41.5 |
| 13, | 23 | 26 | 24.5 | .... | .... | .... | 27 | 30 | 28.5 | 34 | 51 | 42.5 |
| 14, | 29 | 32 | 30.5 | 6 | 6 | 6.0 | 27 | 32 | 29.5 | 51 | 44 | 47.5 |
| 15, | 28 | 32 | 30.0 | 1 | 16 | 8.5 | 30 | 36 | 33.0 | 35 | 31 | 33.0 |
| 16, | 28 | 36 | 32.0 | 7 | 22 | 14.5 | 24 | 24 | 24.0 | 34 | 22 | 28.0 |
| 17, | 37 | 28 | 32.5 | 27 | 32 | 29.5 | 21 | 28 | 24.5 | 28 | 39 | 33.5 |
| 18, | 20 | 15 | 17.5 | 32 | 34 | 33.0 | 35 | 42 | 38.5 | 29 | 38 | 33.5 |
| 19, | 17 | 17 | 17.0 | 25 | 24 | 24.5 | 43 | 20 | 31.5 | 42 | 48 | 45.0 |
| 20, | 10 | 27 | 18.5 | 31 | 37 | 34.0 | 20 | 14 | 17.0 | 49 | 50 | 49.5 |
| 21, | 24 | 31 | 27.5 | 35 | 36 | 35.5 | 12 | 28 | 20.0 | 48 | 43 | 45.5 |
| 22, | 30 | 26 | 28.0 | 32 | 32 | 32.0 | 27 | 36 | 31.5 | 41 | 47 | 44.0 |
| 23, | 24 | 30 | 27.0 | 29 | 30 | 29.5 | 29 | 25 | 27.0 | 48 | 51 | 49.5 |
| 24, | 35 | 27 | 31.0 | 20 | 19 | 19.5 | 18 | 21 | 19.5 | 54 | 52 | 53.0 |
| 25, | 17 | 15 | 16.0 | 16 | 24 | 20.0 | 22 | 28 | 25.0 | 56 | 56 | 56.0 |
| 26, | 21 | 29 | 25.0 | 28 | 34 | 31.0 | 27 | 27 | 27.0 | 56 | 59 | 57.5 |
| 27, | 6 | 6 | 6.0 | 28 | 21 | 24.5 | 23 | 33 | 28.0 | 53 | 54 | 53.5 |
| 28, | 12 | 12 | 12.0 | 21 | 24 | 22.5 | 32 | 35 | 33.5 | 34 | 40 | 37.0 |
| 29, | 3 | 3 | 3.0 | .... | .... | .... | 19 | 27 | 23.0 | 49 | 52 | 50.5 |
| 30, | 13 | 13 | 13.0 | .... | .... | .... | 25 | 31 | 28.0 | 55 | 56 | 55.5 |
| 31, | 11 | 11 | 11.0 | .... | .... | .... | 35 | 29 | 32.0 | .... | .... | .... |
| Means, | 18.6 | 21.0 | 19.8 | 21.8 | 23.9 | 22.8 | 27.1 | 29.2 | 28.1 | 37.4 | 39.9 | 38.6 |

## *Dew Points for 1899—Continued.*

| Dates. | May. | | | June | | | July. | | | August. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 57 | 60 | 58.5 | 63 | 63 | 63.0 | 52 | 56 | 54.0 | 60 | 62 | 61.0 |
| 2, | 61 | 63 | 62.0 | 63 | 56 | 59.5 | 61 | 63 | 62.0 | 66 | 67 | 66.5 |
| 3, | 51 | 55 | 53.0 | 53 | 61 | 57.0 | 64 | 68 | 66.0 | 62 | 66 | 64.0 |
| 4, | 40 | 47 | 43.5 | 62 | 66 | 64.0 | 66 | 69 | 67.5 | 67 | 63 | 65.0 |
| 5, | 46 | 52 | 49.0 | 69 | 71 | 70.0 | 77 | 64 | 70.5 | 68 | 68 | 68.0 |
| 6, | 50 | 55 | 52.5 | 68 | 67 | 67.5 | 64 | 68 | 66.0 | 62 | 53 | 57.5 |
| 7, | 52 | 51 | 51.5 | 67 | 72 | 69.5 | 63 | 66 | 64.5 | 51 | 52 | 51.5 |
| 8, | 56 | 49 | 52.5 | 68 | 58 | 63.0 | 64 | 57 | 60.5 | 53 | 51 | 52.0 |
| 9, | 52 | 45 | 48.5 | 53 | 57 | 55.0 | 56 | 52 | 54.0 | 50 | 62 | 56.0 |
| 10, | 46 | 45 | 45.5 | 56 | 50 | 53.0 | 54 | 57 | 55.5 | 68 | 68 | 68.0 |
| 11, | 53 | 42 | 47.5 | 53 | 53 | 53.0 | 58 | 58 | 58.0 | 66 | 71 | 68.5 |
| 12, | 50 | 53 | 51.5 | 60 | 63 | 61.5 | 62 | 52 | 57.0 | 68 | 68 | 68.0 |
| 13, | 58 | 44 | 51.0 | 66 | 67 | 66.5 | 61 | 58 | 59.5 | 67 | 61 | 64.0 |
| 14, | 38 | 38 | 38.0 | 69 | 70 | 69.5 | 62 | 62 | 62.0 | 53 | 56 | 54.5 |
| 15, | 38 | 44 | 41.0 | 72 | 63 | 67.5 | 64 | 69 | 66.5 | 49 | 55 | 52.0 |
| 16, | 44 | 58 | 51.0 | 46 | 46 | 46.0 | 69 | 70 | 69.5 | 55 | 53 | 54.0 |
| 17, | 51 | 55 | 53.0 | 49 | 55 | 52.0 | 68 | 64 | 66.0 | 55 | 56 | 55.5 |
| 18, | 55 | 55 | 55.0 | 53 | 52 | 52.5 | 56 | 59 | 57.5 | 56 | 68 | 62.0 |
| 19, | 40 | 40 | 40.0 | 55 | 62 | 58.5 | 59 | 62 | 60.5 | 69 | 69 | 69.0 |
| 20, | 42 | 41 | 41.5 | 64 | 63 | 63.5 | 63 | 64 | 63.5 | 61 | 59 | 60.0 |
| 21, | 42 | 47 | 44.5 | 52 | 54 | 53.0 | 67 | 64 | 65.5 | 64 | 65 | 64.5 |
| 22, | 45 | 46 | 45.5 | 53 | 58 | 55.5 | 67 | 71 | 69.0 | 66 | 59 | 62.5 |
| 23, | 45 | 49 | 47.0 | 62 | 71 | 66.5 | 64 | 71 | 67.5 | 59 | 53 | 56.0 |
| 24, | 50 | 49 | 49.5 | 70 | 63 | 66.5 | 68 | 66 | 67.0 | 61 | 64 | 62.5 |
| 25, | 50 | 47 | 48.5 | 64 | 61 | 62.5 | 65 | 66 | 65.5 | 64 | 64 | 64.0 |
| 26, | 49 | 53 | 51.0 | 56 | 55 | 55.5 | 68 | 66 | 67.0 | 64 | 61 | 62.5 |
| 27, | 56 | 61 | 58.5 | 56 | 51 | 53.5 | 68 | 68 | 68.0 | 44 | 62 | 53.0 |
| 28, | 59 | 61 | 60.0 | 63 | 62 | 62.5 | 60 | 64 | 62.0 | 59 | 59 | 59.0 |
| 29, | 61 | 61 | 61.0 | 53 | 50 | 51.5 | 67 | 70 | 68.5 | 55 | 62 | 58.5 |
| 30, | 58 | 57 | 57.5 | 51 | 55 | 53.0 | 57 | 51 | 54.0 | 63 | 63 | 63.0 |
| 31, | 59 | 63 | 61.0 | ........... | ........... | ........... | 55 | 59 | 57.0 | 64 | 66 | 65.0 |
| Means, | 50.1 | 51.1 | 50.6 | 59.6 | 59.8 | 59.7 | 62.9 | 63.1 | 63.0 | 60.3 | 61.5 | 60.9 |

## *Dew Points for 1899—Continued.*

| Dates. | September. | | | October. | | | November. | | | December. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 68 | 67 | 67.5 | 29 | 33 | 31.0 | 45 | 42 | 43.5 | 39 | 42 | 40.5 |
| 2, | 69 | 69 | 69.0 | 30 | 32 | 31.0 | 34 | 27 | 30.5 | 29 | 29 | 29.0 |
| 3, | 66 | 68 | 67.0 | 29 | 39 | 34.0 | 28 | 34 | 31.0 | 33 | 38 | 35.5 |
| 4, | 52 | 53 | 52.5 | 38 | 44 | 41.0 | 31 | 32 | 31.5 | 28 | 24 | 26.0 |
| 5, | 56 | 67 | 61.5 | 41 | 49 | 45.0 | 29 | 35 | 32.0 | 19 | 20 | 19.5 |
| 6, | 68 | 55 | 61.5 | 46 | 42 | 44.0 | 29 | 31 | 30.0 | 24 | 15 | 19.5 |
| 7, | 50 | 59 | 54.5 | 40 | 36 | 38.0 | 28 | 33 | 30.5 | 26 | 26 | 26.0 |
| 8, | 67 | 64 | 65.5 | 42 | 49 | 45.5 | 30 | 40 | 35.0 | 28 | 28 | 28.0 |
| 9, | 53 | 53 | 53.0 | 48 | 49 | 48.5 | 32 | 36 | 34.0 | 27 | 25 | 26.0 |
| 10, | 49 | 56 | 52.5 | 41 | 53 | 47.0 | 43 | 44 | 43.5 | 26 | 36 | 31.0 |
| 11, | 53 | 54 | 53.5 | 48 | 56 | 52.0 | 43 | 39 | 41.0 | 41 | 50 | 45.5 |
| 12, | 55 | 49 | 52.0 | 58 | 57 | 57.5 | 27 | 23 | 25.0 | 52 | 31 | 41.5 |
| 13, | 49 | 44 | 46.5 | 49 | 56 | 52.5 | 21 | 24 | 22.5 | 28 | 25 | 26.5 |
| 14, | 39 | 43 | 41.0 | 52 | 57 | 54.5 | 23 | 30 | 26.5 | 24 | 31 | 27.5 |
| 15, | 42 | 48 | 45.0 | 50 | 55 | 52.5 | 31 | 44 | 37.5 | 23 | 20 | 21.5 |
| 16, | 44 | 56 | 50.0 | 55 | 57 | 56.0 | 41 | 36 | 38.5 | 20 | 16 | 18.0 |
| 17, | 56 | 56 | 56.0 | 56 | 61 | 58.5 | 31 | 38 | 34.5 | 24 | 26 | 25.0 |
| 18, | 57 | 57 | 57.0 | 56 | 54 | 55.0 | 39 | 45 | 42.0 | 26 | 36 | 31.0 |
| 19, | 57 | 62 | 59.5 | 47 | 46 | 46.5 | 51 | 36 | 43.5 | 47 | 26 | 36.5 |
| 20, | 60 | 55 | 57.5 | 42 | 33 | 37.5 | 35 | 35 | 35.0 | 25 | 25 | 25.0 |
| 21, | 50 | 44 | 47.0 | 31 | 29 | 30.0 | 34 | 34 | 34.0 | 22 | 22 | 22.0 |
| 22, | 46 | 53 | 49.5 | 27 | 38 | 32.5 | 39 | 49 | 44.0 | 22 | 30 | 26.0 |
| 23, | 52 | 53 | 52.5 | 40 | 53 | 46.5 | 36 | 29 | 32.5 | 21 | 26 | 23.5 |
| 24, | 55 | 54 | 54.5 | 55 | 55 | 55.0 | 27 | 30 | 28.5 | 33 | 20 | 26.5 |
| 25, | 56 | 56 | 56.0 | 48 | 51 | 49.5 | 28 | 28 | 28.0 | 12 | 10 | 11.0 |
| 26, | 49 | 36 | 42.5 | 45 | 50 | 47.5 | 28 | 31 | 29.5 | 9 | 9 | 9.0 |
| 27, | 39 | 37 | 38.0 | 47 | 52 | 49.5 | 26 | 28 | 27.0 | 10 | 18 | 14.0 |
| 28, | 41 | 49 | 45.0 | 52 | 57 | 54.5 | 27 | 31 | 29.0 | 12 | 12 | 12.0 |
| 29, | 49 | 41 | 45.0 | 50 | 42 | 46.0 | 35 | 36 | 35.5 | 6 | 6 | 6.0 |
| 30, | 34 | 26 | 30.0 | 35 | 42 | 38.5 | 38 | 41 | 39.5 | ........ | ........ | ........ |
| 31, | ........ | ........ | ........ | 37 | 43 | 40.0 | ........ | ........ | ........ | ........ | ........ | ........ |
| Means, | 52.7 | 52.8 | 52.8 | 44.0 | .47.4 | 45.7 | 33.0 | 34.7 | 33.8 | 25.4 | 24.9 | 25.1 |

## *Dew Points for 1899—Continued.*

| Dates. | May. | | | June | | | July. | | | August. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 57 | 60 | 58.5 | 63 | 63 | 63.0 | 52 | 56 | 54.0 | 60 | 62 | 61.0 |
| 2, | 61 | 63 | 62.0 | 63 | 56 | 59.5 | 61 | 63 | 62.0 | 66 | 67 | 66.5 |
| 3, | 51 | 55 | 53.0 | 53 | 61 | 57.0 | 64 | 68 | 66.0 | 62 | 66 | 64.0 |
| 4, | 40 | 47 | 43.5 | 62 | 66 | 64.0 | 66 | 69 | 67.5 | 67 | 63 | 65.0 |
| 5, | 46 | 52 | 49.0 | 69 | 71 | 70.0 | 77 | 64 | 70.5 | 68 | 68 | 68.0 |
| 6, | 50 | 55 | 52.5 | 68 | 67 | 67.5 | 64 | 68 | 66.0 | 62 | 53 | 57.5 |
| 7, | 52 | 51 | 51.5 | 67 | 72 | 69.5 | 63 | 66 | 64.5 | 51 | 52 | 51.5 |
| 8, | 56 | 49 | 52.5 | 68 | 58 | 63.0 | 64 | 57 | 60.5 | 53 | 51 | 52.0 |
| 9, | 52 | 45 | 48.5 | 53 | 57 | 55.0 | 56 | 52 | 54.0 | 50 | 62 | 56.0 |
| 10, | 46 | 45 | 45.5 | 56 | 50 | 53.0 | 54 | 57 | 55.5 | 68 | 68 | 68.0 |
| 11, | 53 | 42 | 47.5 | 53 | 53 | 53.0 | 58 | 58 | 58.0 | 66 | 71 | 68.5 |
| 12, | 50 | 53 | 51.5 | 60 | 63 | 61.5 | 62 | 52 | 57.0 | 68 | 68 | 68.0 |
| 13, | 58 | 44 | 51.0 | 66 | 67 | 66.5 | 61 | 58 | 59.5 | 67 | 61 | 64.0 |
| 14, | 38 | 38 | 38.0 | 69 | 70 | 69.5 | 62 | 62 | 62.0 | 53 | 56 | 54.5 |
| 15, | 38 | 44 | 41.0 | 72 | 63 | 67.5 | 64 | 69 | 66.5 | 49 | 55 | 52.0 |
| 16, | 44 | 58 | 51.0 | 46 | 46 | 46.0 | 69 | 70 | 69.5 | 55 | 53 | 54.0 |
| 17, | 51 | 55 | 53.0 | 49 | 55 | 52.0 | 68 | 64 | 66.0 | 55 | 56 | 55.5 |
| 18, | 55 | 55 | 55.0 | 53 | 52 | 52.5 | 56 | 59 | 57.5 | 56 | 68 | 62.0 |
| 19, | 40 | 40 | 40.0 | 55 | 62 | 58.5 | 59 | 62 | 60.5 | 69 | 69 | 69.0 |
| 20, | 42 | 41 | 41.5 | 64 | 63 | 63.5 | 63 | 64 | 63.5 | 61 | 59 | 60.0 |
| 21, | 42 | 47 | 44.5 | 52 | 54 | 53.0 | 67 | 64 | 65.5 | 64 | 65 | 64.5 |
| 22, | 45 | 46 | 45.5 | 53 | 58 | 55.5 | 67 | 71 | 69.0 | 66 | 59 | 62.5 |
| 23, | 45 | 49 | 47.0 | 62 | 71 | 66.5 | 64 | 71 | 67.5 | 59 | 53 | 56.0 |
| 24, | 50 | 49 | 49.5 | 70 | 63 | 66.5 | 68 | 66 | 67.0 | 61 | 64 | 62.5 |
| 25, | 50 | 47 | 48.5 | 64 | 61 | 62.5 | 65 | 66 | 65.5 | 64 | 64 | 64.0 |
| 26, | 49 | 53 | 51.0 | 56 | 55 | 55.5 | 68 | 66 | 67.0 | 64 | 61 | 62.5 |
| 27, | 56 | 61 | 58.5 | 56 | 51 | 53.5 | 68 | 68 | 68.0 | 44 | 62 | 53.0 |
| 28, | 59 | 61 | 60.0 | 63 | 62 | 62.5 | 60 | 64 | 62.0 | 59 | 59 | 59.0 |
| 29, | 61 | 61 | 61.0 | 53 | 50 | 51.5 | 67 | 70 | 68.5 | 55 | 62 | 58.5 |
| 30, | 58 | 57 | 57.5 | 51 | 55 | 53.0 | 57 | 51 | 54.0 | 63 | 63 | 63.0 |
| 31, | 59 | 63 | 61.0 | ........... | ........... | ........... | 55 | 59 | 57.0 | 64 | 66 | 65.0 |
| Means, | 50.1 | 51.1 | 50.6 | 59.6 | 59.8 | 59.7 | 62.9 | 63.1 | 63.0 | 60.3 | 61.5 | 60.9 |

### *Dew Points for 1899—Continued.*

| Dates. | September. | | | October. | | | November. | | | December. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 68 | 67 | 67.5 | 29 | 33 | 31.0 | 45 | 42 | 43.5 | 39 | 42 | 40.5 |
| 2, | 69 | 69 | 69.0 | 30 | 32 | 31.0 | 34 | 27 | 30.5 | 29 | 29 | 29.0 |
| 3, | 66 | 68 | 67.0 | 29 | 39 | 34.0 | 28 | 34 | 31.0 | 33 | 38 | 35.5 |
| 4, | 52 | 53 | 52.5 | 38 | 44 | 41.0 | 31 | 32 | 31.5 | 28 | 24 | 26.0 |
| 5, | 56 | 67 | 61.5 | 41 | 49 | 45.0 | 29 | 35 | 32.0 | 19 | 20 | 19.5 |
| 6, | 68 | 55 | 61.5 | 46 | 42 | 44.0 | 29 | 31 | 30.0 | 24 | 15 | 19.5 |
| 7, | 50 | 59 | 54.5 | 40 | 36 | 38.0 | 28 | 33 | 30.5 | 26 | 26 | 26.0 |
| 8, | 67 | 64 | 65.5 | 42 | 49 | 45.5 | 30 | 40 | 35.0 | 28 | 28 | 28.0 |
| 9, | 53 | 53 | 53.0 | 48 | 49 | 48.5 | 32 | 36 | 34.0 | 27 | 25 | 26.0 |
| 10, | 49 | 56 | 52.5 | 41 | 53 | 47.0 | 43 | 44 | 43.5 | 36 | 26 | 31.0 |
| 11, | 53 | 54 | 53.5 | 48 | 56 | 52.0 | 43 | 39 | 41.0 | 41 | 50 | 45.5 |
| 12, | 55 | 49 | 52.0 | 58 | 57 | 57.5 | 27 | 23 | 25.0 | 52 | 31 | 41.5 |
| 13, | 49 | 44 | 46.5 | 49 | 56 | 52.5 | 21 | 24 | 22.5 | 28 | 25 | 26.5 |
| 14, | 39 | 43 | 41.0 | 52 | 57 | 54.5 | 23 | 30 | 26.5 | 24 | 31 | 27.5 |
| 15, | 42 | 48 | 45.0 | 50 | 55 | 52.5 | 31 | 44 | 37.5 | 23 | 20 | 21.5 |
| 16, | 44 | 56 | 50.0 | 55 | 57 | 56.0 | 41 | 36 | 38.5 | 20 | 16 | 18.0 |
| 17, | 56 | 56 | 56.0 | 56 | 61 | 58.5 | 31 | 38 | 34.5 | 24 | 26 | 25.0 |
| 18, | 57 | 57 | 57.0 | 56 | 54 | 55.0 | 39 | 45 | 42.0 | 26 | 36 | 31.0 |
| 19, | 57 | 62 | 59.5 | 47 | 46 | 46.5 | 51 | 36 | 43.5 | 47 | 26 | 36.5 |
| 20, | 60 | 55 | 57.5 | 42 | 33 | 37.5 | 35 | 35 | 35.0 | 25 | 25 | 25.0 |
| 21, | 50 | 44 | 47.0 | 31 | 29 | 30.0 | 34 | 34 | 34.0 | 23 | 23 | 23.0 |
| 22, | 46 | 53 | 49.5 | 27 | 38 | 32.5 | 39 | 49 | 44.0 | 22 | 30 | 26.0 |
| 23, | 52 | 53 | 52.5 | 40 | 53 | 46.5 | 36 | 29 | 32.5 | 21 | 26 | 23.5 |
| 24, | 55 | 54 | 54.5 | 55 | 55 | 55.0 | 27 | 30 | 28.5 | 33 | 20 | 26.5 |
| 25, | 56 | 56 | 56.0 | 48 | 51 | 49.5 | 28 | 28 | 28.0 | 12 | 10 | 11.0 |
| 26, | 49 | 36 | 42.5 | 45 | 50 | 47.5 | 28 | 31 | 29.5 | 9 | 9 | 9.0 |
| 27, | 39 | 37 | 38.0 | 47 | 52 | 49.5 | 26 | 28 | 27.0 | 10 | 18 | 14.0 |
| 28, | 41 | 49 | 45.0 | 52 | 57 | 54.5 | 27 | 31 | 29.0 | 12 | 12 | 12.0 |
| 29, | 49 | 41 | 45.0 | 50 | 42 | 46.0 | 35 | 36 | 35.5 | 6 | 6 | 6.0 |
| 30, | 34 | 26 | 30.0 | 35 | 42 | 38.5 | 38 | 41 | 39.5 | ........... | ........... | ........... |
| 31, | ........... | ........... | ........... | 37 | 43 | 40.0 | ........... | ........... | ........... | ........... | ........... | ........... |
| Means, | 52.7 | 52.8 | 52.8 | 44.0 | .47.4 | 45.7 | 33.0 | 34.7 | 33.8 | 25.4 | 24.9 | 25.1 |

## *Meteorological Records for 1899—Relative Humidity (in per cent.)*

| Dates. | January. | | | February. | | | March. | | | April. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 76 | 77 | 76.5 | ........... | ........... | ........... | 75 | 74 | 74.5 | 88 | 89 | 88.5 |
| 2, | 77 | 67 | 72.0 | 86 | 86 | 86.0 | 91 | 91 | 91.0 | 88 | 88 | 88.0 |
| 3, | 79 | 87 | 83.0 | 87 | 95 | 91.0 | 100 | 96 | 98.0 | 88 | 62 | 75.0 |
| 4, | 84 | 81 | 82.5 | 90 | 83 | 86.5 | 95 | 95 | 95.0 | 78 | 64 | 71.0 |
| 5, | 77 | 78 | 77.5 | 100 | 93 | 96.5 | 96 | 79 | 87.5 | 70 | 72 | 71.0 |
| 6, | 100 | 90 | 95.0 | 100 | 100 | 100.0 | 78 | 64 | 71.0 | 70 | 59 | 64.5 |
| 7, | 81 | 85 | 83.0 | 100 | 100 | 100.0 | 85 | 78 | 81.5 | 83 | 96 | 89.5 |
| 8, | 83 | 70 | 76.5 | 100 | 100 | 100.0 | 73 | 76 | 74.5 | 82 | 82 | 82.0 |
| 9, | 80 | 81 | 80.5 | ........... | ........... | ........... | 88 | 83 | 85.5 | 80 | 64 | 72.0 |
| 10, | 81 | 79 | 80.0 | ........... | ........... | ........... | 81 | 76 | 78.5 | 76 | 54 | 65.0 |
| 11, | ........... | ........... | ........... | ........... | ........... | ........... | 83 | 70 | 76.5 | 73 | 56 | 64.5 |
| 12, | 87 | 87 | 87.0 | ........... | ........... | ........... | 81 | 58 | 69.5 | 93 | 47 | 70.0 |
| 13, | 88 | 84 | 86.0 | ........... | ........... | ........... | 80 | 95 | 87.5 | 55 | 61 | 58.0 |
| 14, | 90 | 75 | 82.5 | 87 | 87 | 87.0 | 80 | 75 | 77.5 | 61 | 59 | 60.0 |
| 15, | 73 | 75 | 74.0 | 76 | 65 | 70.5 | 90 | 96 | 93.0 | 60 | 47 | 53.5 |
| 16, | 90 | 96 | 93.0 | 88 | 100 | 94.0 | 79 | 79 | 79.0 | 91 | 51 | 71.0 |
| 17, | 92 | 80 | 86.0 | 95 | 82 | 88.5 | 87 | 73 | 80.0 | 73 | 54 | 63.5 |
| 18, | 76 | 85 | 80.5 | 86 | 91 | 88.5 | 91 | 96 | 93.5 | 70 | 38 | 54.0 |
| 19, | 75 | 75 | 75.0 | 71 | 64 | 67.5 | 100 | 76 | 88.0 | 49 | 53 | 51.0 |
| 20, | 83 | 80 | 81.5 | 62 | 72 | 67.0 | 87 | 73 | 80.0 | 72 | 60 | 66.0 |
| 21, | 79 | 68 | 73.5 | 91 | 66 | 78.5 | 84 | 85 | 84.5 | 76 | 53 | 64.5 |
| 22, | 90 | 72 | 81.0 | 63 | 82 | 72.5 | 89 | 96 | 92.5 | 76 | 63 | 69.5 |
| 23, | 89 | 68 | 78.5 | 81 | 90 | 85.5 | 81 | 71 | 76.0 | 71 | 54 | 62.5 |
| 24, | 96 | 95 | 95.5 | 87 | 86 | 86.5 | 76 | 77 | 76.5 | 78 | 55 | 66.5 |
| 25, | 75 | 85 | 80.0 | 86 | 79 | 82.5 | 88 | 90 | 89.0 | 84 | 84 | 84.0 |
| 26, | 77 | 81 | 79.0 | 90 | 91 | 90.5 | 80 | 80 | 80.0 | 86 | 80 | 83.0 |
| 27, | 81 | 81 | 81.0 | 73 | 68 | 70.5 | 78 | 76 | 77.0 | 83 | 70 | 76.5 |
| 28, | 84 | 84 | 84.0 | 82 | 50 | 66.0 | 91 | 91 | 91.0 | 44 | 39 | 41.5 |
| 29, | 79 | 79 | 79.0 | ........... | ........... | ........... | 86 | 80 | 83.0 | 68 | 53 | 60.5 |
| 30, | 84 | 84 | 84.0 | ........... | ........... | ........... | 89 | 86 | 87.5 | 66 | 54 | 60.0 |
| 31, | 83 | 83 | 83.0 | ........... | ........... | ........... | 96 | 77 | 86.5 | ........... | ........... | ........... |
| Means, | 83.2 | 80.3 | 81.7 | 85.4 | 83.2 | 84.3 | 85.8 | 81.0 | 83.4 | 74.4 | 62.0 | 68.2 |

## *Relative Humidity for 1899—Continued.*

| Dates. | May. | | | June. | | | July. | | | August. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 71 | 95 | 83.0 | 85 | 90 | 87.5 | 73 | 60 | 66.5 | 80 | 59 | 69.5 |
| 2, | 80 | 85 | 82.5 | 90 | 57 | 73.5 | 69 | 60 | 64.5 | 70 | 82 | 76.0 |
| 3, | 78 | 84 | 81.0 | 78 | 72 | 75.0 | 70 | 71 | 70.5 | 77 | 70 | 73.5 |
| 4, | 63 | 67 | 65.0 | 85 | 70 | 77.5 | 64 | 78 | 71.0 | 95 | 60 | 77.5 |
| 5, | 81 | 78 | 79.5 | 75 | 79 | 77.0 | 100 | 76 | 88.0 | 82 | 91 | 86.5 |
| 6, | 88 | 84 | 86 0 | 78 | 68 | 73 0 | 81 | 91 | 86.0 | 85 | 52 | 68.5 |
| 7, | 100 | 54 | 77.0 | 71 | 75 | 73.0 | 81 | 74 | 77.5 | 64 | 55 | 59.5 |
| 8, | 84 | 87 | 85.5 | 78 | 64 | 71.0 | 73 | 79 | 76.0 | 69 | 54 | 61.5 |
| 9, | 83 | 54 | 68.5 | 78 | 75 | 76.5 | 84 | 58 | 71.0 | 72 | 77 | 74.5 |
| 10, | 76 | 54 | 65.0 | 89 | 82 | 85.5 | 66 | 64 | 65.0 | 86 | 82 | 84.0 |
| 11, | 100 | 49 | 74.5 | 83 | 65 | 74.0 | 73 | 61 | 67.0 | 74 | 79 | 76.5 |
| 12, | 62 | 55 | 58.5 | 85 | 85 | 85.0 | 90 | 47 | 68.5 | 78 | 65 | 71.5 |
| 13, | 84 | 57 | 70.5 | 86 | 74 | 80.0 | 65 | 75 | 70.0 | 68 | 62 | 65.0 |
| 14, | 58 | 44 | 51.0 | 78 | 78 | 78.0 | 81 | 72 | 76.5 | 74 | 71 | 72.5 |
| 15, | 58 | 57 | 57.5 | 79 | 77 | 78.0 | 81 | 98 | 89.5 | 60 | 66 | 63.0 |
| 16, | 70 | 94 | 82.0 | 70 | 76 | 73.0 | 91 | 100 | 95.5 | 74 | 55 | 64.5 |
| 17, | 82 | 97 | 89.5 | 72 | 70 | 71.0 | 91 | 95 | 93.0 | 70 | 57 | 63.5 |
| 18, | 89 | 97 | 93.0 | 74 | 55 | 64.5 | 72 | 68 | 70.0 | 71 | 74 | 72.5 |
| 19, | 73 | 73 | 73.0 | 66 | 69 | 67.5 | 68 | 77 | 72.5 | 82 | 62 | 72.0 |
| 20, | 74 | 73 | 73.5 | 66 | 81 | 73.5 | 79 | 81 | 80.0 | 62 | 48 | 55.0 |
| 21, | 79 | 81 | 80.0 | 65 | 62 | 63.5 | 78 | 60 | 69.0 | 60 | 81 | 70.5 |
| 22, | 83 | 76 | 79.5 | 69 | 61 | 65.0 | 71 | 83 | 77.0 | 86 | 65 | 75.5 |
| 23, | 81 | 77 | 79.0 | 69 | 83 | 76.0 | 77 | 79 | 78.0 | 80 | 43 | 61.5 |
| 24, | 88 | 68 | 78.0 | 86 | 95 | 90.5 | 86 | 78 | 82.0 | 76 | 73 | 74.5 |
| 25, | 77 | 63 | 70.0 | 97 | 80 | 88.5 | 90 | 82 | 86.0 | 81 | 77 | 79.0 |
| 26, | 68 | 65 | 66.5 | 71 | 66 | 68.5 | 86 | 64 | 75.0 | 90 | 90 | 90.0 |
| 27, | 84 | 90 | 87.0 | 84 | 52 | 68.0 | 74 | 78 | 76.0 | 95 | 90 | 92.5 |
| 28, | 65 | 62 | 63.5 | 81 | 100 | 90.5 | 76 | 70 | 73.0 | 89 | 76 | 82.5 |
| 29, | 69 | 100 | 84.5 | 78 | 60 | 69.0 | 86 | 68 | 77.0 | 94 | 81 | 87.5 |
| 30, | 75 | 67 | 71.0 | 64 | 63 | 63.5 | 79 | 54 | 66.5 | 85 | 85 | 85.0 |
| 31, | 85 | 85 | 85.0 | ........... | ........... | ........... | 70 | 61 | 65.5 | 77 | 82 | 79.5 |
| Means, | 77.7 | 73.3 | 75.5 | 77.6 | 72.8 | 75.2 | 78.2 | 73.0 | 75.6 | 77.6 | 69.8 | 73.7 |

*Relative Humidity for 1899—Continued.*

| Dates. | September. | | | October. | | | November. | | | December. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 86 | 90 | 88.0 | 74 | 69 | 71.5 | 100 | 79 | 89.5 | 85 | 85 | 85.0 |
| 2, | 91 | 86 | 88.5 | 90 | 75 | 82.5 | 83 | 72 | 77.5 | 81 | 61 | 71.0 |
| 3, | 90 | 68 | 79.0 | 90 | 72 | 81.0 | 73 | 91 | 82.0 | 83 | 96 | 89.5 |
| 4, | 78 | 74 | 76.0 | 84 | 65 | 74.5 | 82 | 82 | 82.0 | 80 | 79 | 79.5 |
| 5, | 84 | 78 | 81.0 | 96 | 79 | 87.5 | 74 | 84 | 79.5 | 86 | 87 | 86.5 |
| 6, | 82 | 66 | 74.0 | 87 | 69 | 78.0 | 74 | 82 | 78.0 | 89 | 85 | 87.0 |
| 7, | 77 | 76 | 76.5 | 85 | 56 | 70.5 | 90 | 83 | 86.5 | ........ | 89 | 89.0 |
| 8, | 78 | 97 | 87.5 | 79 | 97 | 88.0 | 95 | 85 | 90.0 | 73 | 73 | 73.0 |
| 9, | 77 | 74 | 75.5 | 93 | 87 | 90.0 | 82 | 66 | 74.0 | 89 | 71 | 80.0 |
| 10, | 87 | 79 | 83.0 | 100 | 74 | 87.0 | 80 | 86 | 83.0 | 72 | 92 | 82.0 |
| 11, | 94 | 97 | 95.5 | 93 | 74 | 83.5 | 96 | 85 | 90.5 | 88 | 82 | 85.0 |
| 12, | 84 | 56 | 70.0 | 94 | 79 | 86.5 | 80 | 70 | 75.0 | 100 | 62 | 81.0 |
| 13, | 77 | 70 | 73.5 | 97 | 74 | 85.5 | 87 | 79 | 83.0 | 55 | 71 | 63.0 |
| 14, | 72 | 70 | 71.0 | 88 | 75 | 81.5 | 88 | 95 | 91.5 | 79 | 95 | 87.0 |
| 15, | 92 | 71 | 81.5 | 94 | 66 | 80.0 | 90 | 93 | 91.5 | 78 | 87 | 82.5 |
| 16, | 80 | 74 | 77.0 | 94 | 79 | 86.5 | 92 | 92 | 92.0 | 87 | 74 | 80.5 |
| 17, | 79 | 71 | 75.0 | 97 | 90 | 93.5 | 82 | 84 | 83.0 | 89 | 76 | 82.5 |
| 18, | 84 | 71 | 77.5 | 89 | 78 | 83.5 | 85 | 93 | 89.0 | 89 | 66 | 77.5 |
| 19, | 89 | 100 | 94.5 | 87 | 66 | 76.5 | 94 | 71 | 82.5 | 90 | 76 | 83.0 |
| 20, | 97 | 89 | 93.0 | 79 | 69 | 74.0 | 77 | 84 | 80.5 | 89 | 71 | 80.0 |
| 21, | 88 | 75 | 81.5 | 82 | 74 | 78.0 | ........ | 76 | 76.0 | 69 | 51 | 60.0 |
| 22, | 70 | 83 | 76.5 | 80 | 67 | 73.5 | 92 | 82 | 87.0 | 69 | 81 | 75.0 |
| 23, | 88 | 69 | 78.5 | 85 | 65 | 75.0 | 92 | 81 | 86.5 | 87 | 66 | 76.5 |
| 24, | 79 | 62 | 70.5 | 74 | 63 | 68.5 | 72 | 90 | 81.0 | 100 | 67 | 83.5 |
| 25, | 79 | 97 | 88.0 | 97 | 94 | 95.5 | 80 | 80 | 80.0 | 84 | 83 | 83.5 |
| 26, | 97 | 77 | 87.0 | 100 | 60 | 80.0 | 80 | 75 | 77.5 | ........ | 82 | 82.0 |
| 27, | 78 | 66 | 72.0 | 81 | 61 | 71.0 | 95 | 90 | 92.5 | 83 | 86 | 84.5 |
| 28, | 85 | 68 | 76.5 | 83 | 67 | 75.0 | 95 | 86 | 90.5 | ........ | 84 | 84.0 |
| 29, | 77 | 85 | 81.0 | 88 | 79 | 83.5 | 91 | 77 | 84.0 | ........ | 81 | 81.0 |
| 30, | 83 | 65 | 74.0 | 91 | 85 | 88.0 | 84 | 85 | 84.5 | ........ | ........ | ........ |
| 31, | ........ | ........ | ........ | 72 | 100 | 86.0 | ........ | ........ | ........ | ........ | ........ | ........ |
| Means, | 83.4 | 76.8 | 80.1 | 87.1 | 74.4 | 81.1 | 82.8 | 79.9 | 81.3 | 83.0 | 78.0 | 80.5 |

## *Meteorological Records for 1899—Cloudiness—(On the Scale of 10).*

| Dates. | January. | | | February. | | | March. | | | April. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 1 | 0 | 0.5 | 0 | 0 | 0 | 2 | 6 | 4.0 | 10 | 7 | 8.5 |
| 2, | 0 | 0 | 0 | 0 | 10 | 5.0 | 10 | 10 | 10.0 | 6 | 6 | 6.0 |
| 3, | 6 | 10 | 8.0 | 10 | 10 | 10.0 | 10 | 10 | 10.0 | 2 | 6 | 4.0 |
| 4, | 10 | 10 | 10.0 | 10 | 10 | 10.0 | 10 | 10 | 10.0 | 0 | 0 | 0 |
| 5, | 4 | 5 | 4.5 | 10 | 10 | 10.0 | 10 | 10 | 10.0 | 0 | 0 | 0 |
| 6, | 10 | 10 | 10.0 | 10 | 10 | 10.0 | 0 | 8 | 4.0 | 0 | 2 | 1.0 |
| 7, | 0 | 0 | 0 | 10 | 10 | 10.0 | 10 | 3 | 6.5 | 10 | 10 | 10.0 |
| 8, | 0 | 0 | 0 | 10 | 0 | 5.0 | 3 | 10 | 6.5 | 10 | 10 | 10.0 |
| 9, | 8 | 10 | 9.0 | 0 | 0 | 0 | 10 | 10 | 10.0 | 8 | 5 | 6.5 |
| 10, | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 10 | 9.0 | 0 | 0 | 0 |
| 11, | 0 | 0 | 0 | 7 | 10 | 8.5 | 5 | 8 | 6.5 | 0 | 3 | 1.5 |
| 12, | 8 | 10 | 9.0 | 10 | 10 | 10.0 | 8 | 3 | 5.5 | 10 | 0 | 5.0 |
| 13, | 10 | 10 | 10.0 | 10 | 10 | 10.0 | 8 | 6 | 7.0 | 0 | 0 | 0 |
| 14, | 10 | 5 | 7.5 | 0 | 0 | 0 | 0 | 3 | 1.5 | 5 | 5 | 5.0 |
| 15, | 1 | 0 | .5 | 0 | 2 | 1.0 | 10 | 8 | 9.0 | 0 | 5 | 2.5 |
| 16, | 8 | 10 | 9.0 | 8 | 10 | 9.0 | 8 | 9 | 8.5 | 10 | 3 | 6.5 |
| 17, | 10 | 1 | 5.5 | 10 | 0 | 5.0 | 0 | 0 | 0 | 10 | 0 | 5.0 |
| 18, | 6 | 0 | 3.0 | 9 | 10 | 9.5 | 10 | 10 | 10.0 | 0 | 5 | 2.5 |
| 19, | 0 | 0 | 0 | 5 | 0 | 2.5 | 10 | 9 | 9.5 | 2 | 5 | 3.5 |
| 20, | 0 | 5 | 2.5 | 1 | 2 | 1.5 | 1 | 1 | 1.0 | 7 | 3 | 5.0 |
| 21, | 0 | 4 | 2.0 | 5 | 8 | 6.5 | 10 | 8 | 9.0 | 0 | 0 | 0 |
| 22, | 6 | 0 | 3.0 | 7 | 8 | 7.5 | 10 | 9 | 9.5 | 0 | 0 | 0 |
| 23, | 7 | 6 | 6.5 | 3 | 5 | 4.0 | 10 | 9 | 9.5 | 0 | 0 | 0 |
| 24, | 10 | 10 | 10.0 | 7 | 0 | 3.5 | 5 | 1 | 3.0 | 0 | 8 | 4.0 |
| 25, | 6 | 0 | 3.0 | 0 | 0 | 0 | 10 | 10 | 10.0 | 3 | 5 | 4.0 |
| 26, | 3 | 10 | 6.5 | 10 | 10 | 10.0 | 6 | 4 | 5.0 | 3 | 2 | 2.5 |
| 27, | 2 | 0 | 1.0 | 7 | 2 | 4.5 | 4 | 1 | 2.5 | 0 | 0 | 0 |
| 28, | 1 | 0 | .5 | 0 | 3 | 1.5 | 10 | 10 | 10.0 | 0 | 0 | 0 |
| 29, | 7 | 0 | 3.5 | ........... | ........... | ........... | 6 | 10 | 8.0 | 0 | 0 | 0 |
| 30, | 0 | 10 | 5.0 | ........... | ........... | ........... | 9 | 9 | 9.0 | 0 | 3 | 1.5 |
| 31, | 3 | 10 | 6.5 | ........... | ........... | ........... | 10 | 10 | 10.0 | ........... | ........... | ........... |
| Means, | 4.4 | 4.4 | 4.4 | 5.7 | 5.4 | 5.5 | 7.2 | 7.2 | 7.2 | 3.2 | 3.1 | 3.1 |

## *Cloudiness for 1899—Continued.*

| Dates. | May. | | | June. | | | July. | | | August. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 0 | 9 | 4.5 | 10 | 8 | 9.0 | 0 | 0 | 0 | 3 | 1 | 2.0 |
| 2, | 5 | 5 | 5.0 | 10 | 1 | 5.5 | 0 | 0 | 0 | 4 | 3 | 3.5 |
| 3, | 3 | 10 | 6.5 | 1 | 1 | 1.0 | 0 | 3 | 1.5 | 4 | 7 | 5.5 |
| 4, | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 4.0 | 10 | 8 | 9.0 |
| 5, | 0 | 5 | 2.5 | 0 | 1 | .5 | 1 | 8 | 4.5 | 8 | 10 | 9.0 |
| 6, | 0 | 5 | 2.5 | 0 | 3 | 1.5 | 10 | 3 | 6.5 | 5 | 0 | 2.5 |
| 7, | 8 | 5 | 6.5 | 3 | 1 | 2.0 | 0 | 10 | 5.0 | 0 | 1 | .5 |
| 8, | 9 | 10 | 9.5 | 8 | 1 | 4.5 | 8 | 5 | 6.5 | 0 | 1 | .5 |
| 9, | 3 | 0 | 1.5 | 9 | 0 | 4.5 | 9 | 1 | 5.0 | 0 | 2 | 1.0 |
| 10, | 0 | 5 | 2.5 | 10 | 0 | 5.0 | 0 | 0 | 0 | 8 | 10 | 9.0 |
| 11, | 10 | 0 | 5.0 | 1 | 10 | 5.5 | 1 | 9 | 5.0 | 2 | 7 | 4.5 |
| 12, | 2 | 3 | 2.5 | 10 | 10 | 10.0 | 4 | 1 | 2.5 | 1 | 8 | 4.5 |
| 13, | 9 | 0 | 4.5 | 10 | 2 | 6.0 | 2 | 10 | 6.0 | 2 | 1 | 1.5 |
| 14, | 0 | 3 | 1.5 | 6 | 5 | 5.5 | 3 | 1 | 2.0 | 7 | 1 | 4.0 |
| 15, | 3 | 0 | 1.5 | 1 | 2 | 1.5 | 5 | 10 | 7.5 | 1 | 0 | .5 |
| 16, | 8 | 5 | 6.5 | 6 | 5 | 5.5 | 10 | 10 | 10.0 | 0 | 0 | 0 |
| 17, | 9 | 10 | 9.5 | 8 | 1 | 4.5 | 10 | 2 | 6.0 | 0 | 5 | 2.5 |
| 18, | 10 | 1 | 5.5 | 0 | 2 | 1.0 | 4 | 3 | 3.5 | 9 | 1 | 5.0 |
| 19, | 9 | 10 | 9.5 | 1 | 8 | 4.5 | 0 | 3 | 1.5 | 3 | 0 | 1.5 |
| 20, | 4 | 8 | 6.0 | 2 | 3 | 2.5 | 2 | 5 | 3.5 | 1 | 0 | .5 |
| 21, | 9 | 9 | 9.0 | 0 | 0 | 0 | 3 | 1 | 2.0 | 0 | 4 | 2.0 |
| 22, | 1 | 6 | 3.5 | 1 | 0 | .5 | 0 | 0 | 0 | 5 | 2 | 3.5 |
| 23, | 0 | 0 | 0 | 0 | 4 | 2.0 | 0 | 0 | 0 | 10 | 3 | 6.5 |
| 24, | 0 | 2 | 1.0 | 6 | 9 | 7.5 | 8 | 9 | 8.5 | 2 | 4 | 3.0 |
| 25, | 0 | 1 | .5 | 10 | 1 | 5.5 | 10 | 3 | 6.5 | 0 | 7 | 3.5 |
| 26, | 0 | 0 | 0 | 2 | 0 | 1.0 | 3 | 0 | 1.5 | 2 | 10 | 6.0 |
| 27, | 9 | 9 | 9.0 | 3 | 0 | 1.5 | 0 | 0 | 0 | 10 | 10 | 10.0 |
| 28, | 7 | 3 | 5.0 | 5 | 10 | 7.5 | 7 | 4 | 5.5 | 5 | 1 | 3.0 |
| 29, | 0 | 10 | 5.0 | 6 | 0 | 3.0 | 7 | 10 | 8.5 | 5 | 0 | 2.5 |
| 30, | 3 | 1 | 2.0 | 0 | 0 | 0 | 8 | 0 | 4.0 | 9 | 0 | 4.5 |
| 31, | 8 | 10 | 9.0 | ............ | ............ | ............ | 0 | 2 | 1.0 | 3 | 1 | 2.0 |
| Means, | 4.1 | 4.7 | 4.4 | 4.3 | 2.9 | 3.6 | 3.7 | 3.9 | 3.8 | 3.9 | 3.5 | 3.7 |

## *Cloudiness for 1899—Continued.*

| Dates. | September. | | | October | | | November. | | | December. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. | 8 A. M. | 8 P. M. | Mean. |
| 1, | 6 | 10 | 8.0 | 0 | 0 | 0 | 10 | 0 | 5.0 | 8 | 10 | 9.0 |
| 2, | 7 | 0 | 3.5 | 0 | 0 | 0 | 9 | 0 | 4.5 | 0 | 0 | 0 |
| 3, | 0 | 3 | 1.5 | 0 | 0 | 0 | 10 | 10 | 10.0 | 6 | 10 | 8.0 |
| 4, | 8 | 0 | 4.0 | 0 | 0 | 0 | 10 | 0 | 5.0 | 10 | 3 | 6.5 |
| 5, | 2 | 0 | 1.0 | 0 | 0 | 0 | 0 | 10 | 5.0 | 1 | 7 | 4.0 |
| 6, | 0 | 0 | 0 | 10 | 0 | 5.0 | 10 | 0 | 5.0 | 10 | 1 | 5.5 |
| 7, | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 3.0 | 0 | 10 | 5.0 |
| 8, | 8 | 3 | 5.5 | 9 | 10 | 9.5 | 10 | 0 | 5.0 | 9 | 0 | 4.5 |
| 9, | 3 | 3 | 3.0 | 7 | 0 | 3.5 | 0 | 3 | 1.5 | 0 | 0 | 0 |
| 10, | 2 | 4 | 3.0 | 0 | 2 | 1.0 | 10 | 2 | 6.0 | 10 | 9 | 9.5 |
| 11, | 10 | 0 | 5.0 | 8 | 10 | 9.0 | 10 | 8 | 9.0 | 8 | 10 | 9.0 |
| 12, | 0 | 4 | 2.0 | 10 | 0 | 5.0 | 5 | 0 | 2.5 | 10 | 0 | 5.0 |
| 13, | 4 | 0 | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 6 | 6.5 |
| 14, | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 10.0 | 8 | 10 | 9.0 |
| 15, | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 10.0 | 10 | 5 | 7.5 |
| 16, | 0 | 0 | 0 | 10 | 5 | 7.5 | 3 | 6 | 4.5 | 5 | 0 | 2.5 |
| 17, | 0 | 0 | 0 | 10 | 9 | 9.5 | 1 | 8 | 4.5 | 9 | 0 | 4.5 |
| 18, | 2 | 2 | 2.0 | 9 | 8 | 8.5 | 10 | 3 | 6.5 | 8 | 9 | 8.5 |
| 19, | 8 | 10 | 9.0 | 0 | 5 | 2.5 | 10 | 5 | 7.5 | 10 | 0 | 5.0 |
| 20, | 10 | 3 | 6.5 | 9 | 0 | 4.5 | 9 | 4 | 6.5 | 5 | 2 | 3.5 |
| 21, | 10 | 0 | 5.0 | 0 | 2 | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22, | 0 | 0 | 0 | 0 | 3 | 1.5 | 10 | 10 | 10.0 | 0 | 0 | 0 |
| 23, | 0 | 1 | .5 | 0 | 0 | 0 | 10 | 0 | 5.0 | 3 | 10 | 6.5 |
| 24, | 3 | 0 | 1.5 | 1 | 3 | 2.0 | 8 | 0 | 4.0 | 10 | 0 | 5.0 |
| 25, | 9 | 10 | 9.5 | 5 | 4 | 4.5 | 10 | 0 | 5.0 | 6 | 2 | 4.0 |
| 26, | 9 | 5 | 7.0 | 5 | 0 | 2.5 | 8 | 0 | 4.0 | 1 | 1 | 1.0 |
| 27, | 3 | 0 | 1.5 | 10 | 0 | 5.0 | 0 | 0 | 0 | 0 | 10 | 5.0 |
| 28, | 0 | 0 | 0 | 10 | 10 | 10.0 | 0 | 0 | 0 | 4 | 5 | 4.5 |
| 29, | 9 | 0 | 4.5 | 10 | 0 | 5.0 | 8 | 6 | 7.0 | 3 | 2 | 2.5 |
| 30, | 4 | 0 | 2.0 | 5 | 0 | 2.5 | 10 | 0 | 5.0 | 8 | 0 | 4.0 |
| 31, | | | | 9 | 10 | 9.5 | | | | 3 | 0 | 1.5 |
| Means, | 3.9 | 1.9 | 2.9 | 4.4 | 2.6 | 3.5 | 6.9 | 3.1 | 5.0 | 5.6 | 4.0 | 4.8 |

## *Meteorological Records for 1899—Wind.*

| Dates. | January. | | | | February. | | | | March. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | | Velocity in miles per hour. | | Direction. | | Velocity in miles per hour. | | Direction. | | Velocity in miles per hour. | |
| | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. |
| 1, | N | NW | 11 | 3 | W | S | 2 | 15 | N | W | 6 | 6 |
| 2, | S | W | 2 | 2 | SW | SW | 3 | 3 | E | E | 6 | 3 |
| 3, | SE | N | 2 | 2 | S | S | 3 | 7 | E | E | 2 | 2 |
| 4, | SW | S | 3 | 15 | W | SW | 10 | 10 | E | SE | 7 | 9 |
| 5, | S | W | 7 | 7 | E | N | 3 | 3 | S | W | 10 | 25 |
| 6, | E | W | 7 | 7 | NE | E | 7 | 7 | W | W | 7 | 10 |
| 7, | W | W | 15 | 15 | N | NE | 6 | 10 | NW | W | 10 | 32 |
| 8, | W | W | 7 | 7 | W | W | 10 | 15 | NW | W | 18 | 7 |
| 9, | W | W | 3 | 6 | W | W | 10 | 23 | S | SW | 7 | 6 |
| 10, | NE | N | 6 | 3 | W | W | 7 | 10 | W | SW | 3 | 7 |
| 11, | NE | W | 2 | 3 | W | NE | 3 | 6 | S | S | 5 | 5 |
| 12, | N | SW | 3 | 3 | N | N | 6 | 6 | S | W | 10 | 28 |
| 13, | S | W | 2 | 7 | N | NW | 11 | 20 | NW | W | 18 | 7 |
| 14, | N | W | 2 | 15 | W | W | 7 | 7 | E | E | 3 | 6 |
| 15, | W | W | 16 | 7 | W | SW | 2 | 3 | S | SW | 25 | 7 |
| 16, | W | W | 2 | 2 | NE | E | 2 | 2 | W | W | 25 | 18 |
| 17, | S | W | 2 | 7 | W | S | 3 | 2 | W | E | 3 | 3 |
| 18, | N | NE | 11 | 11 | SW | S | 3 | 3 | S | E | 2 | 3 |
| 19, | W | N | 2 | 2 | W | W | 20 | 7 | S | W | 3 | 25 |
| 20, | SW | S | 2 | 2 | W | W | 10 | 3 | W | W | 25 | 10 |
| 21, | S | W | 3 | 17 | S | SW | 7 | 7 | E | W | 3 | 10 |
| 22, | W | W | 12 | 2 | W | W | 10 | 10 | W | W | 2 | 3 |
| 23, | E | S | 3 | 7 | W | W | 7 | 7 | W | W | 15 | 15 |
| 24, | S | N | 2 | 10 | W | W | 10 | 6 | W | W | 22 | 16 |
| 25, | NW | W | 15 | 2 | E | E | 2 | 2 | SW | S | 10 | 7 |
| 26, | W | W | 3 | 16 | S | S | 10 | 10 | W | W | 25 | 7 |
| 27, | W | W | 16 | 7 | W | W | 10 | 20 | E | E | 6 | 6 |
| 28, | W | E | 3 | 3 | W | SW | 3 | 10 | S | E | 15 | 7 |
| 29, | W | W | 10 | 7 | ........... | ........... | ........... | ........... | W | W | 25 | 18 |
| 30, | W | W | 6 | 6 | ........... | ........... | ........... | ........... | W | E | 10 | 7 |
| 31, | W | W | 6 | 10 | ........... | ........... | ........... | ........... | N | W | 3 | 10 |
| Prevailing direction, ...... | W | W | ........... | ........... | W | W | ........... | ........... | W | W | ........... | ........... |

## *Wind for 1899—Continued.*

| Dates. | April. | | | | May. | | | | June. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | | Velocity in miles per hour. | | Direction. | | Velocity in miles per hour. | | Direction. | | Velocity in miles per hour. | |
| | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. |
| 1, | W | W | 10 | 25 | S | S | 3 | 6 | SW | W | 2 | 2 |
| 2, | N | NW | 18 | 18 | SE | S | 3 | 2 | NW | W | 2 | 6 |
| 3, | NW | NW | 10 | 10 | E | S | 9 | 9 | E | E | 2 | 2 |
| 4, | E | E | 7 | 7 | S | SE | 9 | 6 | E | SE | 2 | 5 |
| 5, | E | E | 4 | 4 | SE | S | 3 | 3 | S | W | 2 | 2 |
| 6, | E | S | 3 | 8 | E | S | 2 | 2 | SW | W | 2 | 2 |
| 7, | S | S | 7 | 7 | S | S | 2 | 6 | S | W | 2 | 2 |
| 8, | W | W | 10 | 10 | E | E | 9 | 9 | NW | NW | 6 | 6 |
| 9, | W | W | 10 | 7 | W | W | 3 | 2 | SE | W | 2 | 2 |
| 10, | NW | W | 6 | 6 | W | S | 2 | 2 | E | S | 2 | 2 |
| 11, | E | SE | 3 | 7 | S | W | 6 | 15 | W | S | 2 | 2 |
| 12, | S | W | 3 | 10 | W | O | 6 | 0 | S | S | 6 | 6 |
| 13, | W | W | 3 | 3 | S | W | 10 | 20 | SW | W | 3 | 3 |
| 14, | S | W | 10 | 9 | N | W | 6 | 6 | W | W | 3 | 2 |
| 15, | NW | W | 6 | 9 | S | W | 2 | 6 | W | W | 6 | 9 |
| 16, | S | W | 7 | 15 | E | SW | 2 | 6 | NW | W | 9 | 6 |
| 17, | W | W | 6 | 6 | W | S | 6 | 2 | W | O | 2 | 0 |
| 18, | E | S | 2 | 10 | S | S | 6 | 3 | E | O | 2 | 0 |
| 19, | S | S | 7 | 6 | N | NW | 10 | 10 | W | W | 2 | 3 |
| 20, | S | S | 3 | 6 | NW | NW | 10 | 10 | SW | W | 9 | 8 |
| 21, | E | E | 7 | 10 | N | N | 9 | 3 | NW | W | 6 | 6 |
| 22, | S | S | 6 | 6 | E | E | 3 | 10 | NE | O | 2 | 0 |
| 23, | S | S | 2 | 3 | E | O | 6 | 0 | S | SW | 2 | 2 |
| 24, | S | S | 3 | 7 | E | E | 2 | 2 | W | W | 2 | 2 |
| 25, | S | S | 3 | 3 | S | S | 2 | 2 | W | W | 2 | 3 |
| 26, | E | S | 3 | 7 | S | O | 2 | 0 | E | W | 6 | 3 |
| 27, | E | S | 6 | 9 | SW | SW | 2 | 2 | E | NW | 3 | 2 |
| 28, | S | S | 10 | 9 | NW | W | 10 | 2 | S | SW | 2 | 5 |
| 29, | W | SW | 3 | 6 | W | W | 2 | 2 | NE | N | 9 | 9 |
| 30, | S | S | 3 | 6 | W | W | 6 | 2 | W | O | 2 | 0 |
| 31, | ........ | ........ | ........ | ........ | W | SW | 2 | 2 | ........ | ........ | ........ | ........ |
| Prevailing direction, ...... | S | S | ........ | ........ | SW | W | ........ | ........ | W | W | ........ | ........ |

## *Wind for 1899—Continued.*

| Dates. | July. |  |  |  | August. |  |  |  | September. |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Direction. |  | Velocity in miles per hour. |  | Direction. |  | Velocity in miles per hour. |  | Direction. |  | Velocity in miles per hour. |  |
|  | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. |
| 1, | W | W | 2 | 2 | E | O | 3 | 0 | S | S | 5 | 2 |
| 2, | SW | W | 2 | 2 | SE | S | 2 | 2 | S | W | 2 | 2 |
| 3, | S | SW | 2 | 2 | [illegible] | O | 5 | 0 | W | W | 2 | 5 |
| 4, | SE | O | 2 | 0 | NW | W | 2 | 2 | E | O | 9 | 0 |
| 5, | O | SW | 0 | 5 | NW | NW | 9 | 4 | O | SW | 0 | 1 |
| 6, | W | W | 2 | 2 | N | W | 7 | 7 | E | E | 9 | 9 |
| 7, | S | S | 2 | 2 | N | NW | 3 | 8 | O | S | 0 | 1 |
| 8, | S | W | 2 | 9 | NE | W | 2 | 2 | W | W | 9 | 3 |
| 9, | NW | NW | 9 | 9 | E | O | 2 | 0 | NE | E | 9 | 6 |
| 10, | W | W | 3 | 3 | S | S | 2 | 5 | E | E | 3 | 3 |
| 11, | E | E | 3 | 9 | W | W | 5 | 3 | E | O | 8 | 0 |
| 12, | S | W | 3 | 9 | SE | S | 6 | 6 | W | NW | 5 | 7 |
| 13, | W | SW | 4 | 3 | W | W | 3 | 6 | NW | W | 6 | 6 |
| 14, | W | W | 3 | 3 | N | W | 14 | 4 | W | W | 3 | 2 |
| 15, | E | SE | 3 | 2 | E | E | 10 | 3 | E | O | 1 | 0 |
| 16, | SW | W | 2 | 2 | E | SE | 2 | 2 | E | SE | 2 | 2 |
| 17, | S | SW | 2 | 2 | E | E | 2 | 2 | E | SE | 2 | 5 |
| 18, | W | W | 9 | 3 | NE | E | 9 | 3 | E | SW | 4 | 3 |
| 19, | W | W | 3 | 3 | E | E | 3 | 3 | NW | S | 2 | 2 |
| 20, | E | E | 2 | 5 | W | W | 2 | 2 | W | W | 2 | 2 |
| 21, | W | O | 2 | 0 | O | W | 0 | 2 | NW | W | 5 | 6 |
| 22, | O | S | 0 | 2 | W | W | 3 | 10 | W | W | 2 | 2 |
| 23, | E | SE | 2 | 2 | W | W | 10 | 14 | E | S | 2 | 8 |
| 24, | E | E | 2 | 6 | E | O | 2 | 0 | SE | S | 6 | 20 |
| 25, | SE | SE | 9 | 5 | SE | E | 2 | 2 | S | S | 7 | 3 |
| 26, | W | W | 3 | 3 | NW | NW | 5 | 9 | W | W | 9 | 9 |
| 27, | W | W | 2 | 2 | E | SE | 3 | 10 | N | W | 5 | 6 |
| 28, | NE | W | 2 | 2 | E | O | 5 | 0 | SE | W | 3 | 5 |
| 29, | O | W | 0 | 2 | NW | O | 1 | 0 | S | W | 2 | 5 |
| 30, | NW | W | 7 | 22 | E | S | 2 | 2 | NW | W | 5 | 3 |
| 31, | SE | W | 4 | 7 | S | S | 5 | 3 | ............ | ............ | ............ | ............ |
| Prevailing direction, ...... | W | W | ............ | ............ | E | W | ............ | ............ | E | W | ............ | ............ |

## *Wind for 1899—Continued.*

| Dates. | October. |  |  |  | November. |  |  |  | December. |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Direction. |  | Velocity in miles per hour. |  | Direction. |  | Velocity in miles per hour. |  | Direction. |  | Velocity in miles per hour. |  |
|  | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. | 8 A. M. | 8 P. M. |
| 1, ........ | N | NW | 3 | 3 | E | NW | 9 | 9 | E | W | 3 | 7 |
| 2, ........ | E | E | 2 | 2 | E | NE | 8 | 4 | SW | W | 3 | 6 |
| 3, ........ | E | O | 2 | 0 | E | W | 9 | 8 | O | S | 0 | 3 |
| 4, ........ | E | S | 2 | 2 | W | W | 3 | 6 | W | W | 7 | 15 |
| 5, ........ | N | E | 2 | 2 | W | W | 3 | 9 | W | W | 9 | 7 |
| 6, ........ | E | NE | 6 | 8 | NW | W | 10 | 4 | W | NW | 10 | 9 |
| 7, ........ | E | O | 2 | 0 | W | O | 3 | 0 | E | W | 3 | 10 |
| 8, ........ | E | E | 2 | 2 | E | W | 8 | 3 | W | W | 10 | 4 |
| 9, ........ | S | W | 2 | 3 | W | W | 3 | 7 | W | W | 8 | 3 |
| 10, ........ | S | SW | 3 | 3 | W | W | 10 | 3 | S | SW | 3 | 8 |
| 11, ........ | S | S | 2 | 3 | E | N | 4 | 15 | S | S | 6 | 7 |
| 12, ........ | W | W | 2 | 2 | N | NW | 16 | 4 | SW | W | 3 | 7 |
| 13, ........ | O | O | 0 | 0 | NE | W | 3 | 3 | W | W | 7 | 3 |
| 14, ........ | E | S | 2 | 2 | S | SW | 2 | 3 | E | S | 3 | 7 |
| 15, ........ | E | SE | 2 | 3 | S | S | 3 | 3 | W | W | 10 | 16 |
| 16, ........ | NW | S | 3 | 20 | E | W | 2 | 3 | N | W | 7 | 3 |
| 17, ........ | S | S | 7 | 7 | E | S | 3 | 7 | S | W | 7 | 3 |
| 18, ........ | W | S | 3 | 7 | W | O | 6 | 0 | SW | S | 3 | 6 |
| 19, ........ | O | W | 0 | 3 | S | W | 5 | 7 | W | W | 3 | 3 |
| 20, ........ | NE | N | 9 | 3 | W | W | 7 | 3 | NW | W | 6 | 3 |
| 21, ........ | E | E | 3 | 2 | W | O | 1 | 0 | SW | W | 10 | 15 |
| 22, ........ | W | S | 3 | 3 | SW | E | 1 | 8 | W | W | 7 | 3 |
| 23, ........ | E | S | 2 | 2 | NE | N | 3 | 7 | SW | S | 3 | 15 |
| 24, ........ | W | SW | 3 | 2 | N | O | 1 | 0 | SW | SW | 7 | 22 |
| 25, ........ | E | W | 3 | 3 | N | N | 2 | 2 | W | W | 10 | 7 |
| 26, ........ | SW | S | 3 | 2 | N | W | 2 | 3 | W | SW | 10 | 10 |
| 27, ........ | S | S | 3 | 3 | O | NW | 0 | 1 | W | W | 7 | 8 |
| 28, ........ | NE | S | 3 | 9 | O | W | 0 | 5 | S | S | 7 | 4 |
| 29, ........ | W | W | 9 | 4 | W | O | 2 | 0 | W | W | 7 | 25 |
| 30, ........ | N | NE | 3 | 3 | O | W | 0 | 8 | W | W | 18 | 10 |
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